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MINIMIZING SALT IN RETURN FLOW THROUGH IRRIGATION MANAGEMENT

Final Report

by

U. S. Salinity Laboratory Staff
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16. ABSTRACT

Two field experiments were conducted in southwest Arizona to investigate the potential of reducing the salt load in irrigation return flow by decreased leaching. Three leaching treatments of 5, 10, and 20%, replicated nine times for citrus and five times for alfalfa, were established and compared with conventional flood irrigation management. Annual evapotranspiration of mature Valencia orange trees was 1470 mm. Leaching fractions were close to those intended and 0.47 for the border flood check. During the first four years, the leaching treatments did not influence fruit yield or quality or tree growth. During the last year, however, the yield of the 5% leaching treatment was substantially lower than the other treatments. Thus, with some uncertainty, the leaching requirement for Valencia orange irrigated with Colorado River water exceeds 5% but is less than 20%. Leaching fractions for alfalfa were 0.06, 0.10, and 0.14; near 0.11 for the flood check. Annual evapotranspiration was 1930 mm. After reducing the frequency and increasing the amount of water applied each irrigation, no differences in alfalfa yield (22 Mg ha^{-1}) were noted among treatments or with the flood check. Thus, the leaching requirement of alfalfa with Colorado River water is less than 5%. Both experiments verified that water applications could be reduced substantially below average commercial practice without loss of crop yield. Thus, irrigation return flow and its inherent salt load can be reduced consistent with the leaching requirement for the crop and irrigation water in question.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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FOREWORD

Environmental protection efforts dealing with agricultural and nonpoint sources have received increased emphasis with the passage of the Clean Water Act of 1977 (P.L. 95-217) and the subsequent implementation of the Rural Clean Water Program. As part of this Laboratory's research on the occurrence, movement, transformation, fate, impact and control of environmental contaminants, data and analytical methodologies are developed to assess the causes of and possible solutions to the environmental effects of irrigated agriculture.

The Colorado River Basin exemplifies the complexity of problems encountered in a highly developed river system. Technological solutions are sought for a wide range of problems created by increasing salinity as use of the finite water supply continues to intensify. This report presents results of a study to evaluate the potential of modifying irrigation water management to obtain higher water use efficiency and thus reduce the adverse effects of irrigation on water quality. The results of this study will benefit environmental managers as they identify and implement pollution control strategies relevant to western irrigated agriculture.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental
  Research Laboratory

PREFACE

Irrigation is the largest user of water among all uses. Thus, irrigation management can have a significant impact on water quality. This report concerns a research project that was designed to demonstrate that, through improved irrigation water management, it often is possible to reduce the salt load in irrigation return flow and, thereby, the concentration of dissolved solids in downstream reaches of a river system.

The study was undertaken because of the interest in reducing the salinity of the Colorado River and, more specifically, to address alternative means of meeting the U. S. obligation to deliver to Mexico Colorado River water of specified quality and quantity. It complemented other concurrent studies in Arizona by the U. S. Bureau of Reclamation, the Agricultural Research Service and the University of Arizona, as well as an extensive program of planning and technical assistance by the Soil Conservation Service. It also complemented similar studies by various entities in the Upper Colorado Basin. Together, these studies highlighted the potential of enhancing water resource use by stressing measures to increase on-farm water management.

Jan van Schilfgaarde
Director
U. S. Salinity Laboratory

ABSTRACT

Two field experiments were conducted in the Wellton-Mohawk Irrigation and Drainage District of southwest Arizona to investigate the potential of reducing the salt load in irrigation return flow by decreased leaching. Three leaching treatments of 5, 10, and 20%, replicated nine times for citrus and five times for alfalfa, were established and compared with conventional flood irrigation management.

The annual evapotranspiration of mature Valencia orange trees was found to be about 1470 mm. The leaching fractions, determined indirectly by several techniques, were closed to those intended. The leaching fraction computed for the border flood check was 0.47. During the first four years, the leaching treatments had no observable influence on fruit yield or quality or tree growth. During the last year of study, however, the yield of the 5% leaching treatment was substantially lower than the other treatments. Thus, with some uncertainty, we conclude that the leaching requirement for Valencia orange irrigated with Colorado River water exceeds 5% but is less than 20%.

The leaching fractions in the alfalfa experiment were not exactly as planned. Based on several independent measurement techniques, the actual leaching fractions achieved were 0.06, 0.10, and 0.14; near 0.11 for the flood check. Annual evapotranspiration was estimated to be 1930 mm. After reducing the frequency and increasing the amount of water applied each irrigation, no differences in alfalfa yield were noted among treatments or with the flood check. The annual yield was about 22 Mg ha^{-1}. Thus, the leaching requirement of alfalfa with Colorado River water is less than 5%.

Both the citrus and the alfalfa experiments verified that water applications could be reduced substantially below average commercial practice without loss of crop yield. Thus, irrigation return flow and its inherent salt load can be reduced consistent with the leaching requirement for the crop and irrigation water in question.

This final report was submitted in fulfillment of Interagency Agreement No. EPA-IAG-D6-0370, as amended, by the U.S. Salinity Laboratory, USDA-ARS, under the sponsorship of the U.S. Environmental Protection Agency. An interim report, published in July 1977, covered preliminary results during the period December 1973 through December 1976. This report covers two additional years of data collection and analysis. Field work was completed in 1979.

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SELECTED ABBREVIATIONS AND CONVERSIONS

Symbol	Meaning	Equivalent
ha	hectare	2.47 acres
kg	kilogram	2.205 pounds
kPa	kilopascal	0.15 pounds per square inch
kW	kilowatt	1.34 horsepower
L	liter	0.26 gallons
m	meter	3.3 feet
Mg	megagram	2205 pounds
mol	mole	1 gram-formula weight
$dS\ m^{-1}$	decisiemens per meter	1 millimho per centimeter
$L\ s^{-1}$	liters per second	15.8 gallons per minute
$mg\ L^{-1}$	milligrams per liter	1 part per million
$mol\ m^{-3}$	moles per cubic meter	

Symbol	Meaning
C_T	coefficient in Jensen-Haise ET equation
CEC	cation-exchange capacity
Cl	chloride concentration of soil water
Cl_d	chloride concentration of drainage water
Cl_i	chloride concentration of irrigation water
Cl_z	chloride concentration of soil water at a soil depth z
E_p	pan evaporation
ET	evapotranspiration
f	consumptive use from original Blaney-Criddle equation
f(u)	wind-related function in modified Penman equation
I	depth of irrigation plus rainfall
k_c	crop coefficient
k_i	irrigation factor
k_p	evaporation pan coefficient
k_w	correction for differences in day-night weather conditions
L	leaching fraction
L_r	leaching requirement
p	mean daily percentage of annual daytime hours
R_n	net radiation
R_s	solar radiation
R_{Na}	sodium-adsorption ratio
T	mean of the daily maximum and minimum temperatures
T_x	coefficient in Jensen-Haise ET equation
U	relative water uptake
W	weighting factor in radiation ET equation
W_s	gravimetric water content of soil saturation paste
σ	electrical conductivity of soil water
σ_e	electrical conductivity of saturation extract
$\varepsilon_o - \varepsilon$	difference between saturation and actrual vapor pressure

ACKOWLEDGMENTS

The work reported here was carried out on privately owned land. Without the strong interest and ready cooperation of the land owners, as well as a number of other individuals and organizations, it could not have succeeded.

The orchard where the citrus experiment was conducted changed ownership twice during the course of the experiment. These changes did not affect the research. Mr. C. V. Spencer, President, Spencer and Spencer, the manager of Desert Valencia Ranch, was instrumental in facilitating the original arrangements, including office space and communication. Without him, the experiment could not have been initiated. Later, the managers of Larkin Ranches were most cooperative in permitting us to bring the experiment to conclusion as planned, while Mr. W. M. Wootton provided office facilities.

The alfalfa work was carried out on land of the Snyder Ranch, managed by Mr. Wootton. His keen interest and continued support were deeply appreciated.

The Wellton-Mohawk Irrigation and Drainage District cooperated fully and effectively in providing water and power. This cooperation is gratefully acknowledged.

Although the responsibility for these experiments rested with a group of U. S. Salinity Laboratory scientists located in Riverside, California, the often complicated and important local responsibility to run these elaborate experiments some 420 km from "home base" was entrusted to Robert Ingvalson, soil scientist. When he resigned his position, Mr. Charles Webber took his place. Much of the success of these experiments must be credited to the effective leadership of these two men and the good judgment and hard work of the small group stationed at Tacna, Arizona. This group included at various times Thomas Jereb, Larry Stringer, William Tumblin, Dale Handley, Lyle Haskin, Robert Pine, William Alves, and David Jaskenlski.

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We would also like to acknowledge the able assistance of the remaining U. S. Salinity Laboratory Staff not mentioned here in the installation and operation of these experiments.

SECTION 1

INTRODUCTION

The salt load of the Colorado River poses a major problem. Unless corrective actions are taken, the current average salt concentration of about 850 mg L^{-1} in the lower reaches of the river is expected to increase substantially as further water development takes place (USDI, 1981). Such an increase would have serious economic consequences for the seven states adjoining the river and for the Republic of Mexico (Kleinman and Brown, 1980). Return flow from irrigated lands has been identified by the U. S. Environmental Protection Agency (1971) as a major contributor of salts.

Research at the U. S. Salinity Laboratory led to the conclusion that often the amount of salt in drainage water from irrigated agriculture can be reduced substantially by modifying irrigation management (van Schilfgaarde, et al., 1974; Suarez and Rhoades, 1977). This project was initiated to evaluate the pertinence of this conclusion with particular reference to the Wellton-Mohawk Irrigation and Drainage District in southwestern Arizona, a district where improved irrigation management was a potential alternative to construction of a desalting complex in alleviating the adverse effects of returning brackish drainage water to the river (van Schilfgaarde, 1980).

The primary objective of these field studies was to determine the feasibility of reducing the salt load in drainage water by reduced leaching while maintaining crop yield. Achieving this objective implied increasing irrigation efficiency, using uniform and frequent irrigations with minimal leaching consistent with crop needs; and taking advantage of the reductions in mineral dissolution or increases in salt precipitation as the leaching fraction is reduced. Additional objectives were to determine the components of the water and salt balance under the improved irrigation regimes and to determine the requirements of an irrigation system for these purposes.

One experiment was installed in December 1973 with citrus on coarse-textured mesa soil and continued through fruit harvest in the spring 1979; the second was started in September 1974 with alfalfa on medium-textured valley soil and discontinued in October 1978. The location of these two experiments is illustrated in Fig. 1. Concurrent research, by other groups and by the U. S. Salinity Laboratory, in the same district and in Colorado, addressed corollary issues or parallel questions under different climatic and geologic circumstances. Thus, a concerted effort was mounted during the 1970's to address the relation between agricultural water management and the salinity of the Colorado River.

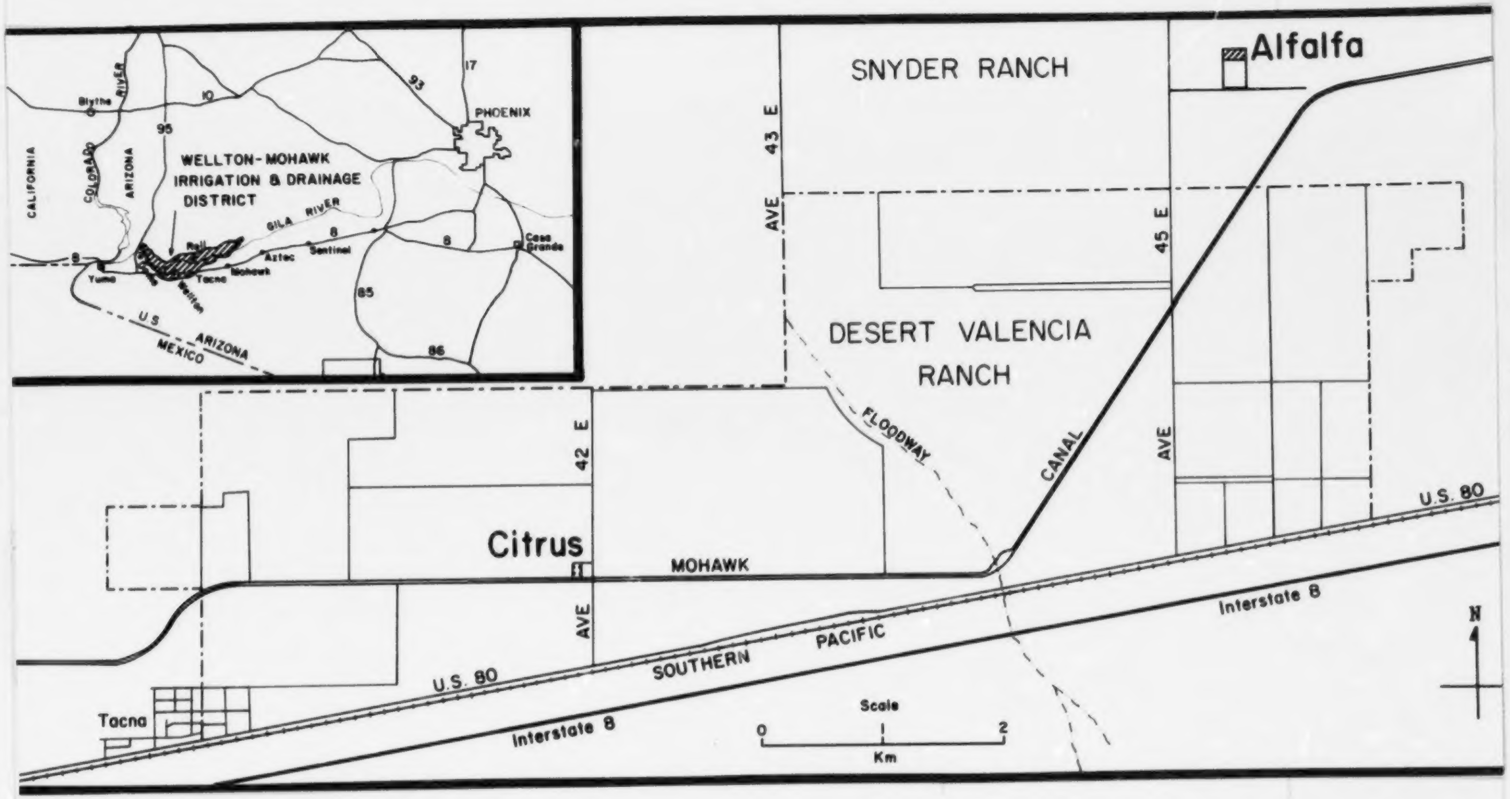
CALIFORNIA
Blythe
COLORADO RIVER
ARIZONA
10
95
93
17
PHOENIX
WELLTON-MOHAWK
IRRIGATION & DRAINAGE
DISTRICT
GILA RIVER
8
Roll
Aztec
Sentinel
Casa Grande
Yuma
Tacna
Mohawk
Wellton
85
86
U.S.
MEXICO
ARIZONA
SNYDER RANCH
Alfalfa
AVE 43 E
AVE 45 E
DESERT VALENCIA
RANCH
FLOODWAY
CANAL
AVE 42 E
Citrus
MOHAWK
U.S. 80
SOUTHERN
PACIFIC
Interstate 8
Tacna
Scale
0
1
2
Km
N

Fig. 1. Location of citrus and alfalfa minimum leaching experiments in southwestern Arizona.

This report describes the two experiments mentioned, reports the results and interprets the findings. Not all objectives were fully attained, but the project succeeded in verifying the basic premise. It also provided useful estimates of the potential changes in the water and salt balances that could realistically be achieved.

SECTION 2

SUMMARY AND CONCLUSIONS

To investigate the potential of reducing the salt load in return flow from irrigated areas by reduced leaching, two field projects were established near Tacna, Arizona, in the Wellton-Mohawk Irrigation and Drainage District. Colorado River water with about 944 mg L^{-1} total dissolved solids (determined analytically; equivalent to 859 mg L^{-1} TDS by residue) was used for irrigation.

In one project, trickle irrigation was used to control the amount of water applied to each tree in a mature Valencia orange orchard located on Dateland fine sandy loam soil. Three treatments replicated nine times, intended to result in leaching fractions of 0.05, 0.10, and 0.20, were established and compared with conventional border flood irrigation. The trickle irrigated plots were irrigated several times a day with a depth of 1.7 mm per irrigation. The irrigation regime was imposed in December 1973 and maintained until fruit harvest in April 1979.

The annual evapotranspiration of the mature citrus trees was found to be close to 1470 mm, a value somewhat higher than indicated in earlier reports. The actual leaching fractions obtained, in contrast to those planned, could not be measured directly. They were estimated from soil salinity, soil water chloride concentration, the salinity of the percolate in buried extractors, and from water balance data. A rather wide range of estimates resulted, but they were consistent with the conclusion that the leaching fractions obtained, averaged over time, were very nearly those planned.

In the first four years, no effect of irrigation treatment was observed on fruit yield or quality. In the last year, a low yield year for all treatments, the yield of the 5% leaching treatment was substantially lower than that of the others. Unfortunately, an unambiguous conclusion on the effect of low leaching levels on citrus yield would have required continuing the experiment for additional years. The data at hand suggest that the fifth year yield depression at low leaching was a real treatment effect. It is possible, but not at all certain, that the capacity of the tree trunks to store chloride delays the negative effect on fruit yield several years after the roots are exposed to higher salinity levels.

With some uncertainty, we conclude that the leaching requirement for Valencia oranges irrigated with Colorado River water exceeds 5% and is less than 20%.

Foliar analysis indicated that nitrogen applications, in the form of foliar urea sprays of 690 g per tree per year, exceeded the nutritional requirement somewhat. Compared with University of Arizona results in an adjacent orchard that 340 g was borderline, a reasonable conclusion would be that 0.5 kg per tree is an adequate level for nitrogen fertilization.

The spatial heterogeneity, the multi-dimensional nature of both the root- and flow-systems, and the temporal cycling prevented the quantitative use of soil salinity data in determining a clear partitioning of the salt in depth and time. However, the data in general were not at variance with expectations. It can be concluded unequivocally that insufficient time elapsed to establish chemical equilibrium in the soil solution with respect to Na, Ca, and Mg, and thus the sodium-adsorption-ratio.

A detailed study of water and salt transport through the root zone was made for one set of nine trees by interruption of the high frequency irrigation for extended periods. Of the water uptake below the surface area wet by the irrigation system (less than half the total surface area), about 80% took place above a depth of 0.60 m. Significant uptake was noted outside the wetted area, with water provided by lateral flow. In summer, serious stress developed in the trees when irrigation was suspended more than 30 days; in winter, interruption up to 60 days showed no ill effects. These results indicate that even in extremely hot climates, citrus under frequent irrigation is not particularly vulnerable to temporary breakdowns of the irrigation system. They also suggest that, if water supplies are limited, it may be practical to practice deficit irrigation in the season of peak evaporative demand, depending on water stored in the soil profile that is replenished in the cool season; adequate fruit yield data were not obtained to verify this suggestion.

Root length distribution data showed a similar pattern to that obtained from water hydraulic head and salt measurements, with substantially more roots at shallow depths (< 0.3 m) under the wetted area, and with 75% of the roots above 0.6 m. In the flood irrigated area, root distribution was more uniform with depth and also with distance from the trunk.

The second project dealt with irrigation of alfalfa on Indio fine sandy loam soil. About 2 ha of an 8-ha field was divided into 15 plots, providing five replications of three treatments. The treatments imposed were expected to yield leaching fractions of 0.05, 0.10 and 0.20. Irrigations were applied with a moving-boom spray system that originally applied a depth of 6 mm of water per pass; after modification, it applied 70 mm per pass. The remainder of the field was irrigated by level basin flooding, applying about 150 mm per irrigation. Alfalfa was seeded early in October 1974 and replanted in October 1976. The experiment ended in October 1978.

The original high frequency irrigation schedule proved incompatible with the other cultural practices. It resulted in excessive compaction and weediness and consequently, in reduced crop yields and poor infiltration. After the irrigation system was modified to accommodate less frequent irrigation, useful results were obtained.

As with the citrus, evapotranspiration was estimated by a number of computational procedures. The best estimate is 1930 mm yr^{-1}.

The leaching fractions actually obtained were not exactly as planned. A reasonable estimate of the actual leaching fractions is 0.06, 0.10 and 0.14; for the flood check, it probably was near 0.11.

Drainage from the nearby mesa caused relatively high water tables in the alfalfa field part of the time. Hydraulic head data showed that, in the 0.05- and 0.10-leaching fraction treatments, the plants used some water from the water table. No such evidence was found for the 0.20-leaching fraction plots.

After replanting, no differences in alfalfa yield were noted among treatments or between the sprinkler irrigated and flood irrigated alfalfa. The annual yield was about 22 Mg ha^{-1}. Thus, the leaching requirement, using Colorado River water, is less than 5%.

Soil samples showed that the field had been well leached prior to the experiment. After establishing the new regimes, the salinity near the surface was lower in the flood check than in the sprinkled plots.

Soil water chloride data indicated that, in the sprinkled plots, 90% of the water was taken up above a depth of 0.6 m. Only 66% of the uptake took place above that depth for the flood check. Root density measurements gave a very similar pattern for the sprinkled plots, but we could not distinguish a different pattern for the flood check; this could have been due to the small number of root samples analysed.

The management of the farmer-irrigated flood check with a leaching fraction of slightly over 0.10, illustrates clearly that high irrigation efficiencies can be obtained and are being obtained commercially. In fact, no advantage can be claimed for the sprinkler system for use on alfalfa. The average efficiency for alfalfa estimated by action agency personnel, however, is substantially lower than the 89% found here. Thus, even if the controlled leaching plots did not use significantly less water than the flood check, the conclusion still is that, especially with the locally well adapted level basin irrigation system, there is ample opportunity for reductions in water use.

Both the citrus and the alfalfa experiments verified that water applications could be reduced substantially below average commercial practice without crop yield reductions. Presumably, the same conclusion could be applied to other crops grown in the area. The consequences of such a reduction, if widely effected, would be several.

Reduced water applications would result in reduced deep percolation and thus, in a reduced drainage flow. In the short run, this reduced flow would have the same salt concentration as at present. At steady state, the reduced flow would have a higher salt concentration than the current drainage flow, because of the salt stored in the aquifer. The concentration would be substantially higher than that expected ultimately were the current water balance maintained.

One can (we did--see Discussion section) make calculations of the changes in salt and water balances per ha for each crop, given a set of assumptions. Suffice it to point out that reducing the drainage flow consistent with the leaching requirement reduces the volume of water required to remove the necessary salt from the system and thus reduces the cost of disposal. By the same amount that the drainage volume is reduced, the amount of water retained in the river for later use is increased.

We propose that the results obtained in these experiments provide evidence to support the assertion that Colorado River diversions into the Wellton-Mohawk District and, consequently, average drainage flow, can be reduced sufficiently, without damaging agricultural production, to make questionable the efficiency of alternative means of salvaging the drainage flows.

SECTION 3

CITRUS

EXPERIMENTAL PROCEDURE

Here we describe the layout of the experiment and the various irrigation and agronomic practices maintained during the study. Also included are detailed descriptions of the various soil and plant parameters measured.

Experimental Design

The citrus experiment, located 3 km east of Tacna, Arizona, on the Desert Valencia Ranch, consisted of nearly 2 ha of trees centered within a 4-ha block planted in the fall of 1963. The experiment was surrounded by similar-age trees, except on the south, where it was bordered by the Mohawk Irrigation Canal. The 4-ha block was chosen based on its history of high yield and the experimental site was located within the block on the basis of the uniformity of tree trunk circumference. The Valencia orange trees (*Citrus sinensis* L.) are Campbell Nucellar budwood grafted on Rough Lemon rootstock. Tree spacing was 4.9 by 6.7 m. The experimental design is illustrated in Fig. 2, which also indicates the coding for each of the plots. The randomized block experiment consisted of three treatments: 5, 10, and 20% leaching. Each treatment was replicated nine times with nine trees per replication in three- by three-tree plots. Based on the analysis of Jones, Embleton, and Cree (1957), this experimental design should permit the statistical detection of 12% yield differences at the 5% level of significance. The experiment was separated from the remainder of the grove by border trees irrigated to achieve 20% leaching.

Soil Properties

Three soil profiles within the experimental site were examined by Soil Conservation Service personnel for characterization and description of the soil morphological properties. A soil description from samples taken by the SCS near the center of the experiment is given in Table A-1 of the Appendix. The soil was classified as Dateland fine sandy loam (Typic Haplargid, coarse-loamy, mixed, hyperthermic) and is representative of the soils where citrus is grown in the district. The soil is calcareous throughout, well drained, and moderately permeable. It is underlain with sand beginning at a depth of 1.5 to 2.0 m and continuing to at least a depth of 4 m. Over 300 soil samples were taken in plots L7, M8, and H6 during December 1973 and again in March 1979 to characterize the initial and final soil chemistry conditions. Sampling traverses were made under the tree canopies in the

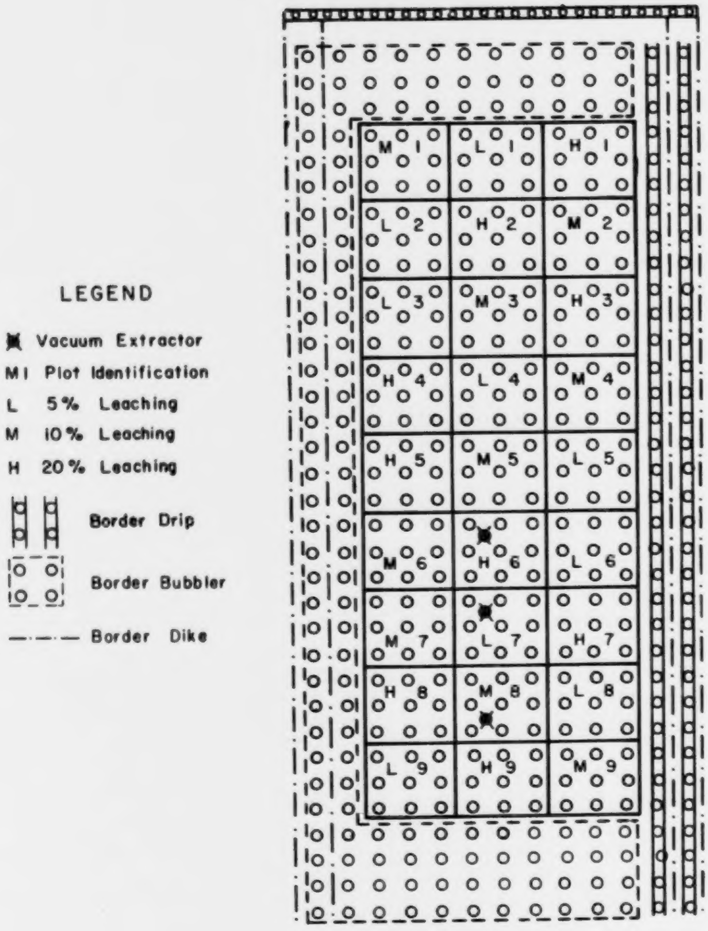
LEGEND
Vacuum Extractor
M1 Plot Identification
L 5% Leaching
M 10% Leaching
H 20% Leaching
Border Drip
Border Bubbler
Border Dike
M1 L1 H1
L2 H2 M2
L3 M3 H3
H4 L4 M4
H5 M5 L5
M6 H6 L6
M7 L7 H7
H8 M8 L8
L9 H9 M9

Fig. 2. Design of minimum leaching experiment on mature Valencia orange trees in southwestern Arizona.

four major compass directions. Samples were collected along each traverse at distances of 1.0, 1.4, 1.8, 2.1, 2.4, and 3.0 m from the tree trunk and at depth intervals of 0 to 0.15, 0.15 to 0.30, 0.30 to 0.60, 0.60 to 0.90, 0.90 to 1.20, and 1.20 to 1.50 m. The samples were mixed and sieved, then analyzed for cation-exchange capacity (CEC), sodium-adsorption ratio (R_{Na}), gravimetric water content of the saturation paste (W_s), electrical conductivity (σ_e) and for the following soluble constituents in saturation extracts: calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate.

The relationship between hydraulic conductivity and matric potential for Dateland fine sandy loam soil was determined in a temperature-controlled laboratory from three 0.9-m-deep, undisturbed soil columns taken in the winter of 1973. Water was applied to the top of the sealed columns by a constant flow device while a vacuum pump was used to maintain a constant suction on the drainage collecting chamber of each column. Miniature tensiometers, spaced 10 cm apart along the length of the columns, were used to measure soil matric potential. The columns were operated for about 9 months. Each time steady state was reached at preset inflow rates, soil matric potentials were recorded and hydraulic conductivity was calculated at each tensiometer depth.

Irrigation

The irrigation water from the Colorado River is delivered to the district in open, concrete-lined canals. The typical concentration of total dissolved salts[1] in the Mohawk Canal during the experiment was 936 g m^{-3}, the mean electrical conductivity was 1.35 dS m^{-1}, and the major salt constituents and their concentrations were Ca, 2.2; Mg, 1.4; Na, 6.4; HCO_3, 2.9; SO_4, 3.6; Cl, 3.7; and NO_3, 0.2 mol m^{-3}. R_{Na} was 3.6 (mol $m^{-3})^{0.5}$. Irrigation water for the experiment was pumped directly from the Mohawk Canal, passed through commercial sand and screen filters, and delivered in buried, plastic mains to each plot at a pressure of about 350 kPa. The filters provided effective filtration of foreign material down to 75 μm in size. The 11-kW centrifugal irrigation pump could deliver 16 L s^{-1}.

The frequency of irrigation and volume of water applied was controlled by programmable time clocks which operated the pump, and automatic irrigation controls at each plot. The time clock for the experimental plots was programmed to operate the pump for 30 minutes three (winter) to seven (summer) times each day. During the summer of 1976 only, the pump operation time was decreased to 15 minutes and the maximum number of irrigations per day was doubled. Flow rate was controlled by a flow control valve so that whenever a plot was irrigated each tree received 30 cm^3 s^{-1}. For an application period of 30 minutes, this irrigation rate was equivalent to a uniform application of 1.7 mm over the land surface area allotted each tree. The volume of water applied to each plot of nine trees was measured by two water meters placed in series to insure accurate measurements. Each of the 243 experimental trees was irrigated with a 35-m long spiral of dual-chamber, drip-irrigation tubing as shown in Figs. 3 and 4. The tubing had 0.5-mm-diameter outlets every 30 cm along its length; the supply orifices between chambers were spaced 1.5 m apart. This design was chosen to enhance uniform water application under each tree. Figure 5 is a photograph of the irrigation system in operation under one of the experimental trees.

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[1] The 936 g m^{-3} reported is the sum of the analytically determined dissolved solutes. The equivalent concentration in terms of total dissolved solids as determined by evaporation is 845 g m^{-3}. For this conversion of dissolved to residue constituents, it was assumed that all constituents would result in anhydrous salts upon evaporation and that all bicarbonate in solution would exist as carbonate in the residue. The bicarbonate in solution was divided by 2.03 to determine its equivalent weight as carbonate in the residue.

The border trees were irrigated by a second programmable time clock that operated the pump and automatic irrigation controls several times daily during periods when the experimental plots were not being irrigated. The two border rows along the west side of the experiment and trees bordering the experiment on the north and south were irrigated by bubblers filling small basins formed under each tree (see Fig. 4). The water delivery rate of each bubbler was controlled at 60 cm^3 s^{-1} by a flow control valve. The two border rows along the east side of the experiment and the closely spaced trees on the north edge of the block were irrigated with capillary tubes (1.7-mm ID) inserted inside 25-mm-diameter polyethylene pipe (see Fig. 4). The pipe was laid on the soil surface about 1 m out from both sides of the trunk of the trees. The capillary tube outlets were spaced 70 cm apart, giving 14 emitters per tree. Flow control valves in each pipeline were set for an average delivery of 30 cm^3 s^{-1} to each tree.

Instrumentation

From the beginning of the experiment until January 1977 each plot was irrigated automatically based on the readings of four tensiometers installed at the 0.3-m soil depth and located 60 degrees apart 1.5 m from the trunk of the center tree of each plot (Fig. 3). To sense soil matric potential, a light-emitting diode and a phototransistor were placed directly opposite each other on the manometer tubing of the tensiometers as shown in Fig. 6 (Austin and Rawlins, 1977). As the soil dried, rising mercury in the manometer column interrupted the light beam from the diode. This electrically opened a water valve to irrigate the plot whenever the pump was operated. To help overcome variability and to guard against tensiometer failure, at least two of the four tensiometers had to call for water before the electrical signal opened the valve. Irrigation frequency was controlled by the location (setpoint) of the phototransistor on the manometer tubing. Lowering the setpoint raised the soil matric potential (less negative) and increased leaching; raising the setpoint decreased leaching.

From January 1977 until the termination of the experiment, the automatic control with tensiometers was replaced by manual control based on pan

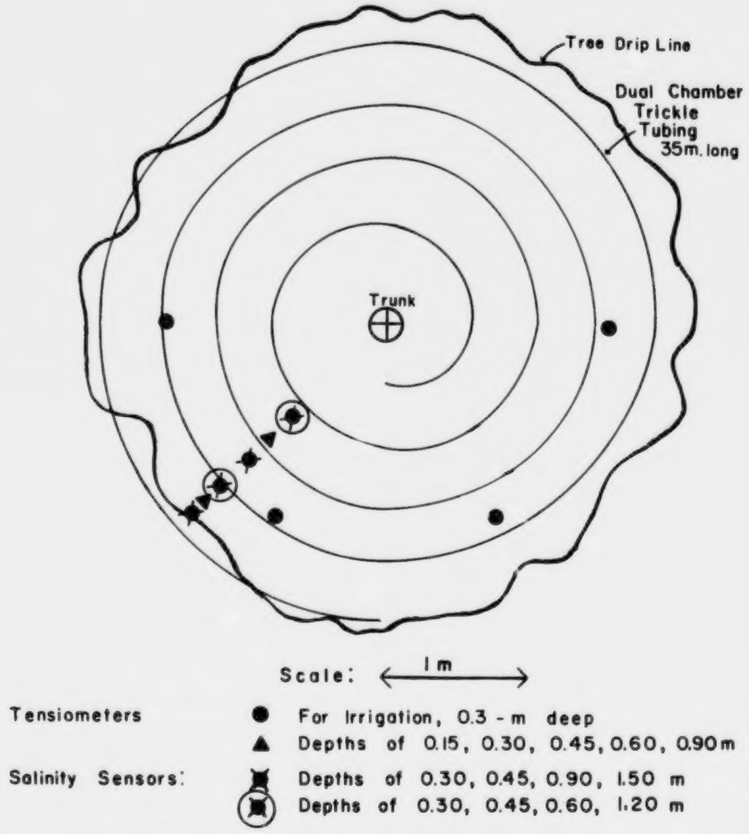
Tree Drip Line
Dual Chamber Trickle Tubing 35m. long
Trunk
Scale: 1 m
Tensiometers
● For Irrigation, 0.3 - m deep
▲ Depths of 0.15, 0.30, 0.45, 0.60, 0.90 m
Salinity Sensors:
✱ Depths of 0.30, 0.45, 0.90, 1.50 m
⊛ Depths of 0.30, 0.45, 0.60, 1.20 m

Fig. 3. Illustration of instrumentation under center tree of three of the nine replications for each leaching treatment. The remaining replications have two sets of salinity sensors and one set of tensiometers.

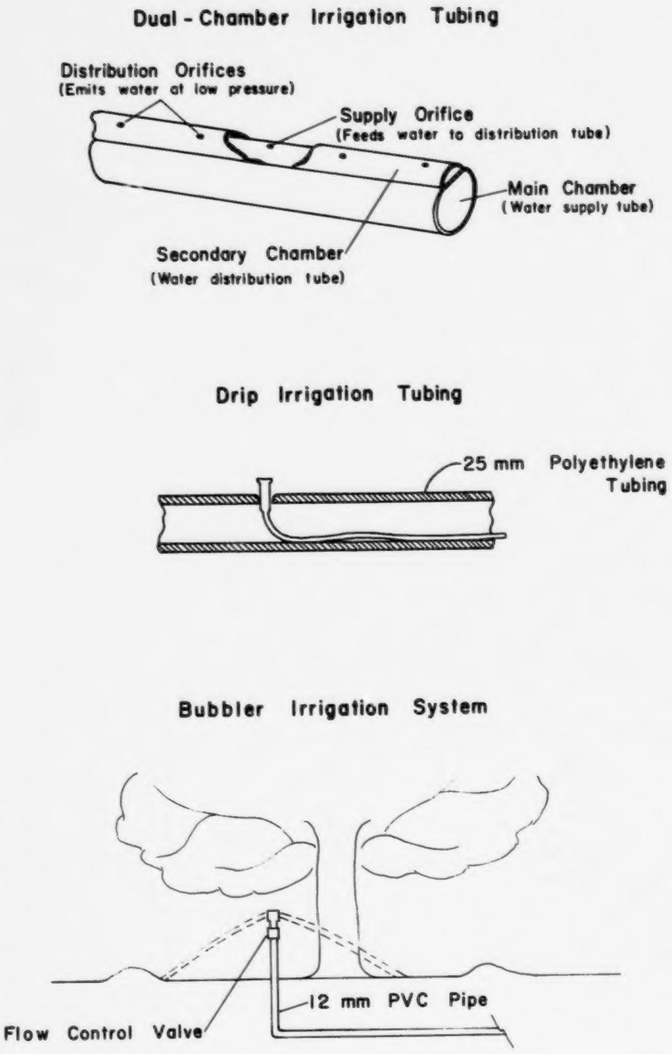
Dual - Chamber Irrigation Tubing
Distribution Orifices
(Emits water at low pressure)
Supply Orifice
(Feeds water to distribution tube)
Main Chamber
(Water supply tube)
Secondary Chamber
(Water distribution tube)
Drip Irrigation Tubing
25 mm Polyethylene Tubing
Bubbler Irrigation System
12 mm PVC Pipe
Flow Control Valve

Fig. 4. Sketch of dual-chamber, bubbler, and drip irrigation systems.

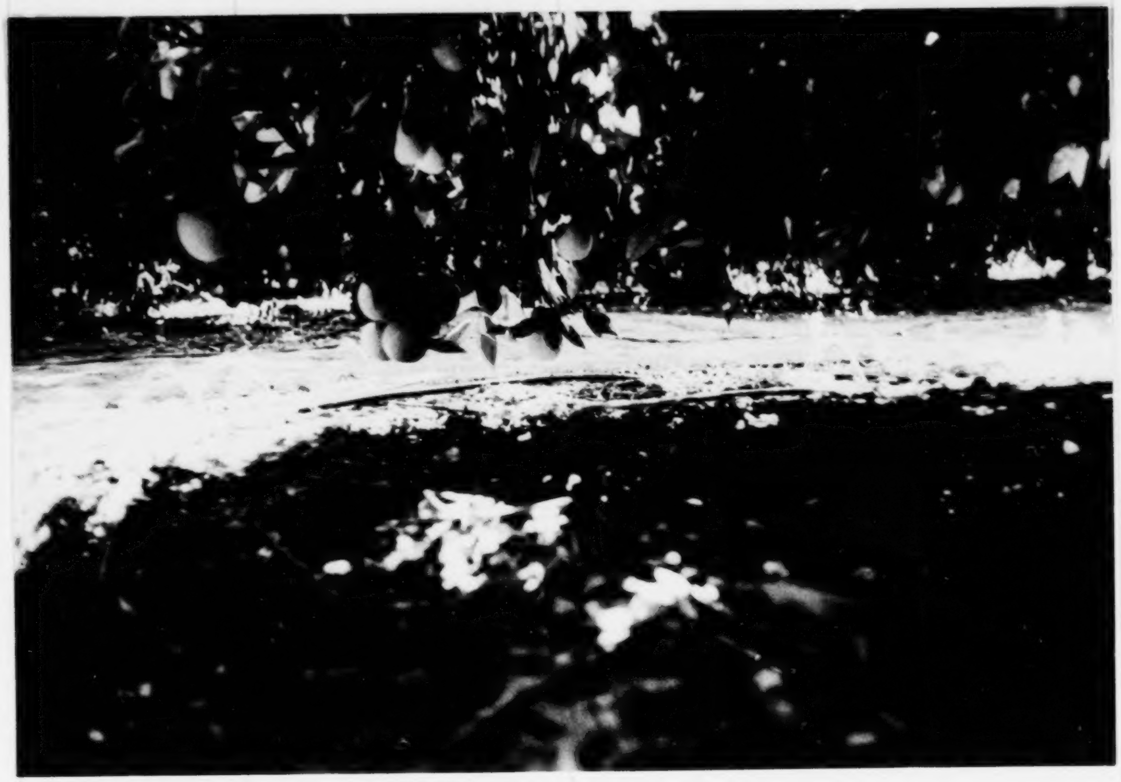

Fig. 5. Irrigation in progress for one of the experimental trees.

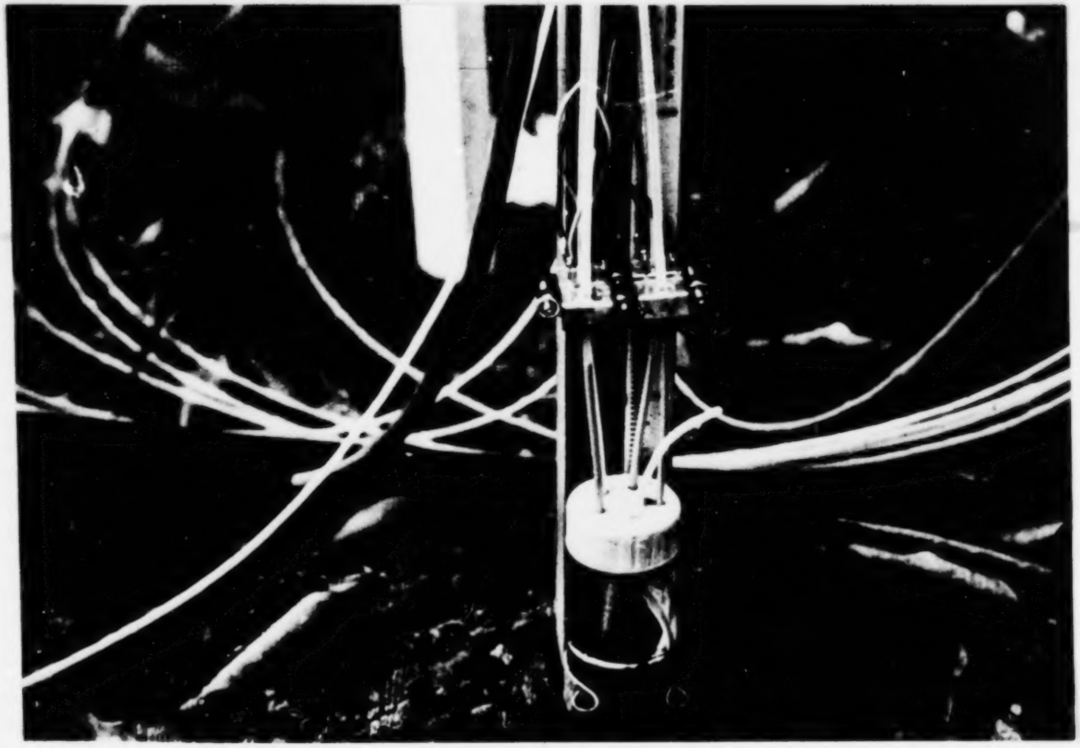

Fig. 6. Light-emitting diode and a phototransistor placed opposite each other on the manometer columns of four irrigation tensiometers on one plot.

evaporation measured within the grove. Pan evaporation was monitored at two locations in southwest Arizona. Both pans were the standard Class A Weather Bureau type. One pan was located about 0.5 km north of the experiment within the Valencia orange grove in place of a tree. The second pan was located at the Mesa Experiment Station of the University of Arizona near Yuma, about 70 km west of the experiment. Temperature, solar radiation, daily wind travel, and humidity were monitored 2 km east of the experiment.

Salinity sensors (Richards, 1966) and additional tensiometers in two spatial distributions were installed beneath the center tree of each plot. For three of the nine replications for each leaching treatment, four sets of salinity sensors and two sets of tensiometers were installed along one radial (see Fig. 3). All the tensiometers and the salinity sensors at 0.15-, 0.30-, and 0.45-m soil depths were installed in December 1973, and those at 0.60- and 0.90-m depths were installed in June 1974. The radial distances out from the trunk for the salt sensors were 0.9, 1.3, 1.6, and 1.9 m. Initially, the salinity sensors were installed at relatively shallow soil depths because of the expected time lag in salinity buildup with depth and the need for responsive salinity feedback to control irrigation. During October and November 1974, the soil salinity at a depth of 0.9 m began to increase. In addition, the soil salinity measurements at the 0.15-m depth equaled or exceeded that at 0.30 m and they also tended to fluctuate more. Because the leaching fraction and soil salinity at the bottom of the root zone were of primary interest, the sensors buried at a depth of 0.15 m were reinstalled at depths of either 1.2 or 1.5 m in March 1975. Thereafter, the pattern of salinity sensors for these three replications was four sensors at depths of 0.30 and 0.45 m and two at depths of 0.6, 0.9, 1.2, and 1.5 m. In the remaining six replications, salinity sensors were installed at depths of 0.30 and 0.45 m at distances of 1.2 and 1.6 m from the trunk on the same radial line. Tensiometers, at the depths given in Fig. 3, were installed midway between the salt sensor locations. The salinity sensors and tensiometers were read twice weekly.

Four vacuum extractors were installed in one replication of each of the three leaching treatments to measure the leaching rate and the chemical composition of the soil solution below the undisturbed root zone (Duke and Haise, 1973). Within a treatment, extractors were directed toward the center of four different trees from a common manhole. A diagram of the extractors is given in Fig. 7; note location in Fig. 2. Each extractor consisted of three independent sheet-metal troughs 15 cm wide by 20 cm high by 61 cm long. The extractors were installed in a rectangular tunnel formed by first augering a horizontal hole at a soil depth of 1.2 m and then forcing a rectangular shaper into the hole. Each extractor contained two lines of ceramic tubes 12 mm in diameter (see Fig. 8A) and was filled flush with the top with soil removed in forming the tunnel (see Fig. 8B). The extractors were raised against the smooth ceiling of the tunnel by inflating a butyl rubber air pillow. Soil solution was collected in a small sample bottle in each extractor drain line just ahead of a large collection bottle held under partial vacuum. With sufficient flow, the contents of the small sample bottles were continually replaced by fresh soil water, providing samples in equilibrium with the partial pressure of the soil CO_2. Initially an attempt

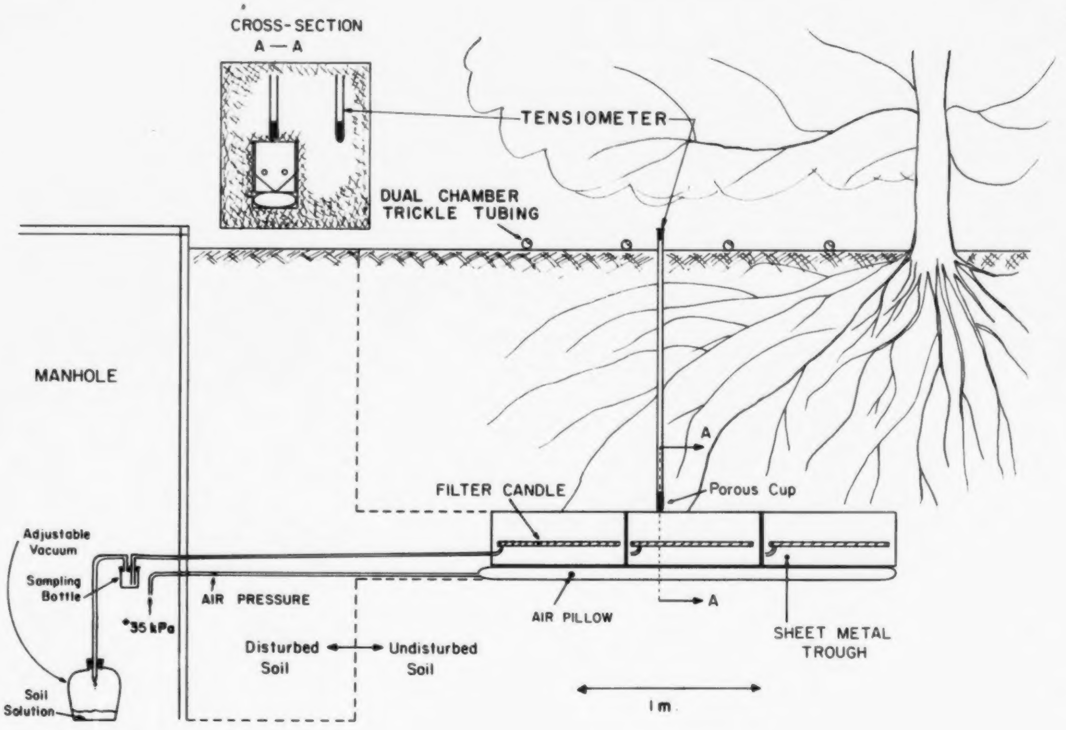
CROSS-SECTION
A — A
TENSIOMETER
DUAL CHAMBER
TRICKLE TUBING
MANHOLE
A
FILTER CANDLE
Porous Cup
Adjustable
Vacuum
Sampling
Bottle
AIR PRESSURE
+35 kPa
AIR PILLOW
A
SHEET METAL
TROUGH
Disturbed
Soil
Undisturbed
Soil
Soil
Solution
1 m

Fig. 7. Schematic of vacuum extractor installation in the citrus experiment.

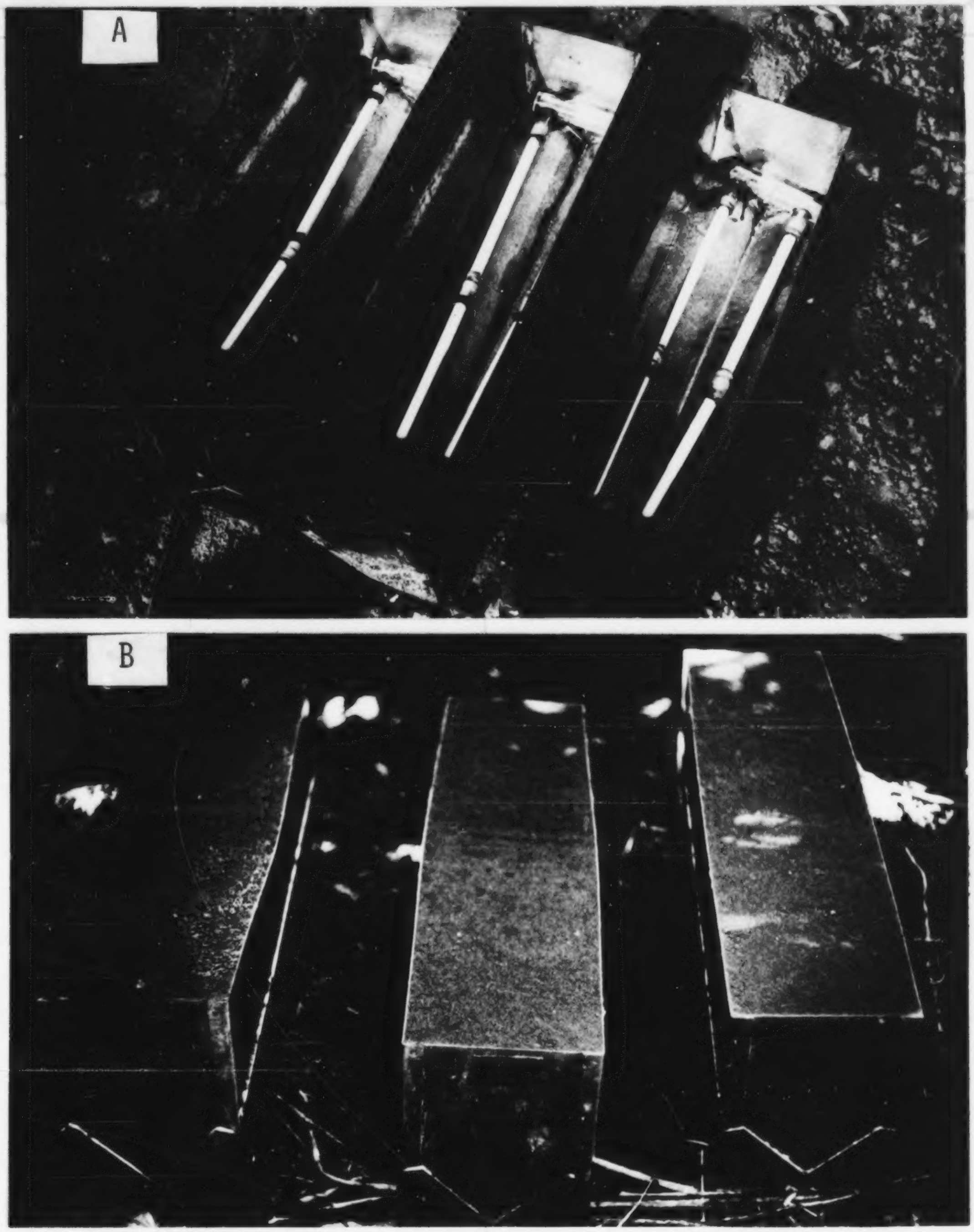

Fig. 8. Set of three extractors being prepared for installation in the citrus experiment. (A) shows the ceramic tubes in the bottom of each extractor and (B) is a photograph after the extractors are filled with soil.

was made to adjust the vacuum in the collection bottles so that two tensiometers over the center of the extractor read the same as two tensiometers about 30 cm away from the extractor at the same depth (see inset in Fig. 7). With uniform soil matric potentials in the horizontal plane at their tops, the extractors should intercept the flux representative of their cross-sectional area without causing convergence or divergence of flow. However, the tensiometers over the extractors were found to be insensitive to the suction in the filter candles, and generally read the same as those in the undisturbed soil. As a consequence no further effort was made to adjust the suction in the extractors to balance the tensiometer readings and the suction was maintained at about 3.0 m of water.

Between January and June 1977, several attempts were made to improve the installation of the extractors in plots H6 and L7. These attempts were undertaken because the volumes of leachate from these extractors were less than anticipated based on soil solution and leachate chloride concentrations. The extractors were removed, repacked with soil, repaired if needed, and, in the case of L7, saturated with irrigation water. For H6 the ceramic extractors were wetted by backflushing through the vacuum lines with irrigation water. The ceiling of each tunnel was recut just prior to the reinstallation of the extractors.

To study in detail the dynamics of water and salt transport in the soil and water uptake distribution during irrigation, as well as the response when irrigation is interrupted, a large number of instruments were installed in March 1975 under the center tree of plot H4. Tensiometers were installed at 0.6-m intervals along radial lines out from the trunk at soil depths ranging from 0.3 to 1.8 m. Pairs of access tubes were installed in October 1976 for gamma-ray attenuation probe and neutron probe measurements of volumetric soil water content. During the installation of the access tubes, soil samples were taken at 0.1-m intervals down to a depth of 1.5 m for determination of soil bulk density, volumetric water content, and chloride concentration.

Soil Chloride Sampling

Soil samples were taken at various times (see Tables 1 and 2) to determine the chloride distributions with depth and distance from the tree. Soil chloride concentration was determined on extracts (prepared by the addition of 10 g of water to 10 g of oven-dry soil) and expressed as mol m^{-3} at field water content. Table 1 lists the dates of sampling and the plots sampled, indicating the number of replications and the depth intervals sampled. The chloride data from these samples, all taken about 1.2 m from the tree trunk, were used to assess water uptake distribution and soil salinity patterns with depth. They were supplemented by additional samples along various radials and at distances extending beyond the tree canopy (Table 2). These additional data were used to evaluate the spatial variation in water uptake and, from that, the leaching fraction and the evapotranspiration.

TABLE 1. SOIL SAMPLING SITES BENEATH THE TREE CANOPY AT A DISTANCE BETWEEN 1.1 AND 1.4 m FROM THE TRUNK FOR CHLORIDE ANALYSIS

Sampling Depth Date	Plots Sampled			No. of trees Sampled	No. of Sites Per Tree	Code for * Sampling Increments
	L	M	H			
Dec. 1974	3,5,7	----	3,4,6	3	3	1
Dec. 1975	5	----	-----	2	1	2
Mar. 1976	7	----	4	2	3	2
Dec. 1977	1,5,6	2,4,7	4,7,8	3	3	3
Mar. 1979	1,5,6	2,4,7	4,7,8	3	3	3

*Code 1: 0-0.05, 0.05-0.10, 0.1-0.2....1.5-1.6 m; samples for each site analyzed separately.

Code 2: Same as Code 1 except sampling depth increased to 1.8 m.

Code 3: 0.2-0.3, 0.5-0.6, 0.8-0.9, 1.1-1.2, 1.4-1.5 m; samples from the three sites of each tree composited before analysis.

Root Sampling

Soil samples were obtained in April 1979 from five replicates of each leaching treatment and the flood check to determine the spatial distribution of root length as a function of leaching. Samples from the three leaching treatments were taken along three traverses from the center tree along the west, southwest and south directions. For the former two directions, the samples were taken at distances of 1.5, 2.1, and 2.7 m from the trunk, whereas for the south traverse the distances were 1.5 and 2.1 m. In the flood treatment, an additional site at 3.3 m on the southwest radial was sampled. For the 5 and 20% leaching treatment, additional root data were obtained from the soil samples taken to characterize the final soil chemistry conditions. Soil samples, obtained with an 83-mm diameter auger to a depth of 1.2 m, were divided into 0.15-m increments to a depth of 0.3 m and into 0.3-m increments at greater depths.

Roots were separated from the bulk of the soil in the field by wet sieving. The roots and remaining material were kept in cold storage until final separation by floatation. The length of large roots (> 3 mm in diameter) was measured directly, but that of smaller roots was calculated from their dry weight (60°C) and an experimentally determined relationship

TABLE 2. SOIL SAMPLING SITES ALONG VARIOUS RADIALS FROM THE TRUNK OF THE CENTER TREE IN A PLOT

Sampling Date	Plots Sampled		Radials Sampled	Distances out from Trunk m	Sampling Code*
	L	H			
Dec. 1974	–	6	E,W;	0.7,1.9,2.1,2.7,3.3**	1
Feb. 1975	7	4	N,S;	0.6,1.2,1.8,2.4	1
			NE,SW;	1.6,2.2,2.8,2.4,4.0	1
			E,W;	0.6,1.2,1.8,2.4,3.0	1
Mar. 1976	7	4	N;	0.6,1.2,1.8,2.4	1
			SW;	1.6,2.2,2.8,3.4,4.0	1
			W;	0.6,1.2,1.8,2.4,3.0	1
Oct. 1976	–	4	S;	0.9,1.2,1.7,2.1,2.4	2
			SW;	2.4,2.8,3.4,3.7,4.3	2
			W;	1.2,1.5,2.0,2.4,2.8	2
Dec. 1976	5	–	N;	0.6,1.2,1.8,2.4	1
			SW;	1.6,2.2,2.8,3.4,4.0	
			W;	1.2,1.8,2.4,2.0	
Dec. 1977	–	4	W;	1.8,2.3,2.9	3
			SE;	1.8,2.4,3.0,3.6,4.2	3
	5	–	W;	1.8,2.3,2.9	3
			SW;	1.8,2.4,2.9,3.4,3.9	3
Mar. 1979	–	4	W;	1.8,2.3,2.9	4
			SE;	1.8,2.4,3.0,3.6,4.2	4
			SW;	1.8,2.4,3.0,3.6,4.2	4
	5	–	W;	1.8,2.3,2.9	4
			SW;	1.8,2.4,3.0,3.6,4.2	4
	7	–	SW;	1.8,2.4,3.0,3.6,4.2	4

*Code 1: 0-0.05, 0.05-0.1, 0.1-0.2, ..., 1.7-1.8 m
Code 2: 0-0.05, 0.05-0.1, 0.1-0.2, ..., 1.4-1.5 m

Code 3: 0-0.1, 0.2-0.3, 0.4-0.5, ..., 1.8-1.9 m

Code 4: 0-0.2, 0.2-0.4, 0.4-0.6, ..., 1.4-1.6 m

** Samples taken from radials around three trees.

between root weight (W, g) and root length (L, km), L = 3.1 W; $r^2 = 0.86$. This relationship was established by measuring L using the line-intersect method (Newman, 1966) on 10% of the samples.

Irrigation Management

The ultimate objective of the experiment required that leaching at the bottom of the root zone be controlled precisely. Since routine measurements of water flux below the root zone are not feasible, our management scheme was to control the salinity at the bottom of the root zone at a level corresponding to that predicted for the imposed leaching fraction. Because of the lag between changes in water application and corresponding changes in soil salinity with depth, the irrigation system was controlled by readings from shallow tensiometers the first 3 years of the experiment. Irrigation was applied whenever the soil water pressure head at a soil depth of 0.3 m decreased below a predetermined setpoint. Such control of soil water pressure head can assure adequate water for plant growth, but it is not a practical method for attaining a prescribed leaching fraction. Raats (1974) demonstrated that, at steady state, there is a unique relation between pressure head, leaching fraction and root uptake pattern for uniform soils. In practice, the relationship between hydraulic conductivity and pressure head is variable, root uptake pattern varies with time, and total rate of water uptake varies also. At steady state, there is also a unique relation between the soil salinity within the root zone and leaching fraction provided the root uptake pattern is relatively constant as should be the case for mature trees. Thus, if irrigation management is based on both soil water pressure head and salinity measurements, some degree of control is assured with regard to the objective of providing adequate water at a controlled leaching fraction (Oster et al., 1976). Based on this hypothesis, irrigation management, during the first 3 years, was based on tensiometer setpoints which were adjusted biweekly on the basis of soil salinity.

The initial values of soil salinity at the 0.3-m soil depth used for control were estimated from salinity distributions calculated by means of the soil water composition model of Oster and Rhoades (1975). These distributions depend on the chemical composition of the irrigation water, the partial pressure of CO_2 in the soil, and the water uptake pattern of the crop, as well as the leaching percentage. Using the water uptake data for citrus reported by Erie et al. (1965) and a typical Colorado River water composition, we calculated the target salinities as a function of depth. For example, at the depth (0.3 m) where 44% of the water has been taken up for a target L = 0.2, the effective leaching fraction is

$$L_e = 1.0 - 0.44\ (1 - L) = 0.65. \qquad (1)$$

On this basis, it was estimated that the target salinities at 0.3 m were 1.8, 2.0 and 2.2 dS m^{-1} for the 20, 10, and 5% leaching treatments with corresponding values at the bottom of the root zone of 5.3, 9.5, and 16.9 dS m^{-1}, respectively (Table 3). The tensiometer setpoints were chosen

TABLE 3. PREDICTED SOIL SOLUTION COMPOSITIONS* AND VARIOUS MEASURES OF SOIL SALINITY AT STEADY STATE AS A FUNCTION OF LEACHING FRACTION

Leaching Fraction	σ	R_{Na}	Cations			Anions		
			Ca	Mg	Na	HCO_3	SO_4	Cl
	dS m^{-1}	(mol $m^{-3})^{1/2}$	mol m^{-3}					
0.03	24.7	28	12.6	47	213	9.3	81	130
0.05	16.9	20	13.2	28	128	7.6	62	78
0.10	9.5	12	12.2	14	64	6.4	36	39
0.15	6.9	10	9.5	9	43	6.4	24	26
0.20	5.3	8	7.9	7	32	6.4	18	20
0.30	3.7	6	6.4	5	21	6.4	12	13
0.40	2.8	5	5.6	4	16	6.4	9	10

* Assuming the partial pressure of CO_2 is 2 kPa and the irrigation water composition in mol m^{-3} is; Ca, 2.2; Mg, 1.4; Na, 6.4; HCO_3, 2.9; SO_4, 3.6, and Cl, 3.9.

initially on the basis of best judgment. Decisions on adjustment of the tensiometer setpoints for each plot were based on biweekly evaluation of the soil salinity, the matric potential profile, and amount of irrigation water applied. As knowledge was gained from soil chloride distribution, leachate volumes and salt concentrations from the vacuum extractors, soil salinity deeper in the profile, and the partial pressure of CO_2 in the soil, the target salinity levels at the 0.3-m soil depth were also changed. Table 4 lists the projected salinity values used as feedback in controlling irrigation.

Four tensiometers were installed under one tree for each of the two borders to control irrigation. Because the water application geometry for the borders was different from that of the experimental plots, the tensiometer setpoints were adjusted so that the same amount of water was applied to the borders as the average application for the 20% leaching treatment. Salinity sensors were not used as feedback to control irrigation for the borders.

During the last 2 years of the study, pan evaporation data were used to predict the appropriate irrigation amounts. The objective of using pan evaporation with soil salinity feedback was to eliminate the time lag

TABLE 4. ALTERATIONS OF THE PROJECTED ELECTRICAL CONDUCTIVITY OF THE SOIL WATER (dS m^{-1}) AT THE 0.3-m DEPTH TO ACHIEVE THE DESIRED LEACHING IN THE CITRUS EXPERIMENT

Date	Leaching Treatment		
	5%	10%	20%
Dec. 1973	2.2	2.0	1.8
Aug. 1974	3.4	2.9	2.4
Jan. 1975	2.9	2.6	2.1
Mar. 1975	2.8	2.5	2.2
Sep. 1976	3.6	2.9	2.2

between evaporative demand and water application which occurred when tensiometers were controlling the irrigation system and soil salinity was used as the feed-back. From the relationship between evapotranspiration (ET) estimated from previous years' data and the evaporation, E_p, from the pan located within the grove, an irrigation factor, k_i, was determined. The irrigation requirement (irrigation plus rainfall), I, for each leaching treatment, L, was calculated as $I = k_i E_p/(1-L)$. A k_i value of 0.84 was used from January to August 1977. Thereafter, because of high salinities which persisted for several months, k_i was increased to 0.95 except for August 1978when it was 1.0. Adjustments in irrigation rate were made weekly to maintain cumulative water application as closely as possible to a preset fraction of pan evaporation. To simplify management, all plots received the water requirement for ET daily, taking into account rainfall, and the extra amount of water required for each leaching treatment was added once a week.

Check Plots

The citrus grove on the ranch was irrigated by border flooding; a border consisted of six rows of 35 trees each, a total area of 0.7 ha, surrounded by earthen dikes. A typical border irrigation consisted of a 15-cm deep application over the entire area within the border. The water was applied to each border in about 45 minutes through six sliding gates in the concrete wall of the irrigation lateral. Such a border (flood check) was selected for comparison in the 4-ha block of trees immediately north of the experiment. Soil water pressure head was monitored under three separate trees with tensiometers as described above. Because of the high leaching percentage, the soil salinity level was very low and was monitored periodically from soil samples. For yield and quality comparison, 27 trees from each of three rows in the middle of the border were harvested individually. Total water applications for each irrigation were determined by measuring flow rate with a concrete, critical-flow flume (Replogle, 1977) installed in the irrigation lateral and irrigation period with elapsed-time devices installed on the irrigation outlets. Flow rate in the lateral could be calculated to within about 2% from the known flume geometry and by continuously recording water elevation at the entrance to the flume relative to the flume floor at its throat.

One border of flood irrigated trees just east of the experiment within the same 4-ha block was fertilized by foliar application, as were the experimental trees, rather than through the irrigation water as was done throughout the grove. This border (fertilizer check) was also used for yield comparisons with the experimental trees.

Yield and Fruit Quality

The fruit from all the experimental trees, the two rows of border trees parallel with the experimental trees on both the east and west sides, and three rows of trees from both the flood and fertilizer check plots were harvested by individual trees in April of each year and weighed. The number of fruit per tree was determined by counting the number of fruit in one field box from each tree and calculating the total number from the average weight per fruit.

Just before harvest, four fruit were picked from each experimental tree for quality analysis. Three samples of 12 fruit each were also picked from the borders and the flood and fertilizer check plots. Measures of fruit quality included: fruit length and width, fruit mass, rind color and texture, and ring size. Ring size is equivalent to the average number of fruit contained in a standard-size shipping carton. After the fruit analyses, the juice was extracted and analyzed. Juice analysis included total soluble solids, total acid, and percent juice.

Tree Growth and Leaf Analysis

A simple measure of tree growth often used in citrus research is trunk enlargement with time. Although the trees were over 10 years old, they were not fully mature, and trunk circumference was measured in September 1973, July 1974, August 1975, July 1976, July 1977, July 1978, and March 1979. In 1974, a nail was driven into each trunk to locate permanently the measurement elevation.

A program of leaf analysis was initiated in March 1974 and continued each year thereafter for the purpose of nutritional evaluation, fertilizer recommendations, and detection of possible toxic levels of individual elements. Because leaf analysis standards are based on 4- to 10-month-old leaves sampled in the fall, all subsequent samples were taken in September or October for analysis. Leaf samples were taken from every tree in the experimental plots and from every third tree in the border and check plots. Each sample consisted of 72 leaves obtained by sampling eight leaves from each of nine trees per plot. Leaves that represented average foliar conditions were taken from the ends of non-fruiting terminal branches at two heights on four sides of each tree. Handling, cleaning, and preparation of the leaf samples for analysis were done according to established procedures (Chapman, 1967).

Complete analyses for 13 mineral elements were made at the U. S. Salinity Laboratory. Nitrogen was determined by the micro-Kjeldahl method; P by molydovanadate colorimetry; Ca, Mg, Na, Fe, Mn, Zn, and Cu by atomic absorption spectroscopy; K by flame emission spectroscopy; Cl by amperometric-coulometric titration; S gravimetrically by precipitation of $BaSO_4$; and B by carmine colorimetry.

Agronomic Practices

Except for fertilization, all crop management operations such as frost protection, pruning, and insect and weed control were performed by the ranch to match those given the surrounding groves. The experimental trees were fertilized with foliar sprays of urea and microelement chelates. Foliar application was chosen to permit uniform fertilizer applications to each tree while differential water applications were made, to minimize nitrate discharge in the leachate, to avoid further salt additions to the irrigation water, and to minimize the amount of fertilizer required. Nitrogen as low-biuret urea was applied to each tree six times each spring at a rate of 115 g N per tree per application. Chelates of iron, zinc, and manganese were also applied with some nitrogen applications at the rates of 1.0, 1.0, and 0.5 g per tree per year, respectively.

Soil Air

With frequent irrigations to maintain the soil water pressure head high, soil aeration may be a problem, particularly in heavy soils. Even though no aeration problems were expected in the sandy loam soil of the citrus experiment, soil oxygen concentrations were measured during both the winter and summer of 1975, in cooperation with Dr. Burl Meek of the Imperial Valley Conservation Research Center in Brawley, California, with polarigraphic probes installed at the 45-cm soil depth and about 1.5 m radially out from the tree trunk.

Because the carbon dioxide concentrations in the soil-air phase will affect the chemical composition of the drainage waters, soil-air samples were obtained by attaching evacuated plastic bags to porous aeration stones buried in the soil. The carbon dioxide content of the soil-air samples was determined with an infrared gas analyzer.

Incidence of Phytophtera

To evaluate the difference between drip and border flood irrigation on the incidence of Phytophtera, a visual reconnaissance was made in April 1979 throughout the entire 4-ha block of trees where this experiment and the drip irrigation experiment conducted by the University of Arizona were located. The occurrence of Phytophtera in 42 rows of 35 trees each and irrigated by border flood was compared with that in 74 rows of drip-irrigated trees.

RESULTS

Soil Properties

The average initial values of selected soil chemical properties and their standard deviations of the mean are summarized in Table 5. At the beginning of the experiment, soil salinity, as indicated by the electrical conductivity of the saturation extract (σ_e), was low and the ion composition was consistent with that expected following prolonged irrigation with Colorado River water at a high leaching fraction. The calcium to magnesium ratios for the soil solution and the river water (See p.4) were about 2.0. The sulphate to chloride ratios were near 1.0. The sodium adsorption ratio, R_{Na}, of the river water and that of the soil water above a depth of 0.3 m were near 3.5 $(mol\ m^{-3})^{1/2}$. The R_{Na} of 5.2 in the 0.9- to 1.2-m depth interval corresponds to that expected with a leaching fraction of 0.65. The chloride concentration of 5.3 mol m^{-3} corresponds to a leaching fraction of 0.40. A few moderately saline zones of apparent restricted permeability were found in some samples. These zones of low permeability also exhibited above average exchange capacity which indicates high clay content.

The spatial variability of the initial soil solution chemical data increased with soil depth. The coefficient of variation, the ratio of the standard deviation to the mean, in the 0- to 0.15-m depth interval was typically 0.24. In the 0.90- to 1.2-m depth interval, it was 0.78. Based on an analysis of skewness and kurtosis by depth, the ion concentrations were normally distributed in the surface soil layer, but skewed at greater depth; the means were consistently greater than the medians. Consequently, although the standard deviations at depths below 0.15 m do not accurately describe the distributions of soil solution chemical data about the respective means, they were included in Table 5 to indicate the extent of variability between individual measurements. For data obtained above 0.15 m, the standard deviations and means do describe the distribution of the data.

Analyses of soil samples obtained at the end of the experiment are summarized in Table 6. Leaching treatment effects on ion concentrations and the related parameters of σ_e and R_{Na}, evident in the 0.15- to 0.30-m depth interval, became pronounced at greater depths. The exceptions were potassium, bicarbonate, and nitrate. These exceptions arose from (1) low potassium concentration in the irrigation water and its high cation exchange selectivity coefficient, (2) high calcium relative to bicarbonate concentrations in the irrigation water and (3) low concentrations of nitrate in the irrigation water. In contrast to the soil solution chemical data taken at the initiation of the experiment, the coefficient of variation decreased with depth, as did the tendency for skewness. Except for chloride and nitrate, these data were normally distributed below a depth of 0.30 m. Consequently, the same cautions stated above, with regard to the use of standard deviation as a measure of the distribution of skewed data obtained below 0.15 m, apply here to data obtained above 0.3 m. Both spatial uniformity of water application and water uptake pattern appeared to affect the distribution of the data about the mean. Past irrigation by flooding, which spread

TABLE 5. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES AT THE BEGINNING OF THE CITRUS EXPERIMENT

Soil Depth	σ_e	R_{Na}	W_s	CEC	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
m	dS m^{-1}	$(mol\ m^{-3})^{1/2}$	kg kg^{-1}	mol kg^{-1}	-----------------	mol m^{-3}	-----------------					
0-0.15	1.2	3.3	0.27	108	2.0	1.1	5.8	0.3	3.1	2.4	2.2	2.6
	(0.2)*	(0.3)	(0.03)	(4)	(0.4)	(0.2)	(0.7)	(0.1)	(0.7)	(0.6)	(0.6)	(1.3)
0.15-0.3	1.2	3.5	0.23	105	1.9	1.0	6.0	0.2	2.1	3.0	3.0	1.2
	(0.2)	(0.4)	(0.03)	(2)	(0.3)	(0.2)	(0.9)	(0.1)	(0.4)	(0.6)	(0.6)	(0.6)
0.3-0.6	1.3	3.9	0.26	112	2.0	11.0	6.9	0.2	1.8	4.0	3.0	0.6
	(0.8)	(1.0)	(0.04)	(3)	(2.0)	(0.6)	(5.1)	(0.1)	(0.4)	(4.6)	(1.1)	(0.2)
0.6-0.9	1.5	4.9	0.30	114	2.2	1.2	9.0	0.2	1.8	5.0	3.9	0.4
	(1.0)	(2.0)	(0.04)	(3)	(2.0)	(0.8)	(7.9)	(0.1)	(0.5)	(5.4)	(2.9)	(0.2)
0.9-1.2	1.9	5.2	0.31	110	3.0	1.5	11.0	0.2	1.6	6.2	5.3	0.7
	(1.2)	(1.8)	(0.05)	(3)	(2.6)	(1.1)	(8.0)	(0.1)	(0.5)	(5.5)	(4.8)	(0.8)

* Standard deviation assuming normal distribution.

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TABLE 6. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES AT THE END OF THE CITRUS EXPERIMENT AS A FUNCTION OF LEACHING TREATMENT

Soil Depth	Leaching Treatment	σ_e	R_{Na}	W_s	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
m	%	dS m^{-1}	$(mol\ m^{-3})^{1/2}$	kg kg^{-1}	----------	----------	----------	----------	mol m^{-3}	----------	----------	----------
0-0.15	5	2.5	4.6	0.27	5.0	2.6	12.4	0.4	2.0	7.6	7.7	2.4
		(1.5)*	(1.2)	(0.03)	(4.4)	(1.7)	(5.3)	(0.4)	(0.6)	(4.4)	(9.9)	(2.0)
	10	2.5	4.7	0.25	4.6	2.7	13.0	0.4	2.0	7.8	7.1	3.2
		(1.8)	(1.8)	(0.03)	(4.5)	(2.5)	(10.7)	(0.2)	(0.8)	(6.5)	(9.8)	(2.6)
	20	2.2	4.6	0.25	3.8	2.1	11.0	0.3	1.6	7.0	5.1	2.5
		(0.9)	(1.6	(0.02)	(2.2)	(1.2)	(5.6)	(0.2)	(0.8)	(5.2)	(1.7)	(1.0)
0.15-0.30	5	3.2	6.0	0.22	6.0	3.4	17.8	0.4	1.4	10.2	12.1	1.7
		(1.4)	(1.3)	(0.05)	(4.3)	(2.4)	(6.6)	(0.2)	(0.3)	(5.8)	(11.3)	(1.6)
	10	2.7	6.1	0.23	4.4	2.6	15.5	0.3	1.5	8.4	9.7	1.8
		(1.8)	(1.6)	(0.06)	(4.8)	(2.8)	(8.4)	(0.2)	(0.4)	(5.7)	(12.2)	(1.8)
	20	2.9	5.9	0.21	4.6	2.5	15.9	0.4	1.3	8.9	9.8	1.9
		(1.6)	(2.0)	(0.02)	(3.2)	(1.9)	(10.0)	(0.4)	(0.7)	(5.4)	(7.4)	(2.0)
0.3-0.6	5	3.8	6.9	0.25	6.8	3.8	22.1	0.4	1.3	14.6	12.0	1.4
		(1.3)	(1.3)	(0.02)	(3.4)	(2.0)	(7.8)	(0.1)	(0.3)	(6.8)	(8.6)	(1.2)
	10	3.2	6.6	0.27	4.9	3.4	19.0	0.4	1.4	11.0	10.4	1.4
		(1.7)	(2.0)	(0.05)	(3.2)	(2.8)	(10.9)	(0.2)	(0.3)	(7.2)	(8.1)	(1.2)
	20	2.9	6.4	0.22	4.6	2.5	16.8	0.3	1.3	9.4	9.7	1.4
		(1.9)	(1.5)	(0.02)	(4.0)	(2.2)	(9.8)	(0.2)	(0.3)	(6.0)	(7.4)	(1.6)
0.6-0.9	5	5.2	8.4	0.28	9.4	5.8	32.6	0.5	1.1	21.1	18.5	1.0
		(1.5)	(1.0)	(0.03)	(3.4)	(2.2)	(9.0)	(0.1)	(0.3)	(7.0)	(9.4)	(0.5)
	10	4.0	7.2	0.30	6.8	4.2	24.0	0.4	1.2	14.8	14.5	0.9
		(2.0)	(1.6)	(0.06)	(4.1)	(3.0)	(12.1)	(0.2)	(0.3)	(8.8)	(9.8)	(1.0)
	20	3.7	7.3	0.25	6.3	4.0	22.0	0.3	1.1	14.0	12.6	0.9
		(2.2)	(1.3)	(0.02)	(5.1)	(3.7)	(10.9)	(0.1)	(0.2)	(8.4)	(13.0)	(1.0)
0.9-1.2	5	5.0	8.7	0.29	8.5	5.2	31.7	0.4	1.0	18.4	20.1	1.0
		(1.2)	(1.3)	(0.04)	(3.2)	(2.1)	(7.1)	(0.1)	(0.3)	(4.8)	(10.3)	(0.7)
	10	4.3	7.9	0.32	7.2	4.6	27.0	0.4	1.1	16.3	16.0	0.9
		(2.1)	(1.5)	(0.08)	(4.4)	(3.2)	(13.5)	(0.3)	(0.2)	(8.5)	(10.2)	(0.7)
	20	4.0	7.3	0.26	7.0	4.4	23.9	0.3	1.0	14.6	16.2	0.6
		(1.7)	(1.1)	(0.02)	(4.3)	(2.8)	(9.6)	(0.1)	(0.4)	(6.0)	(14.0)	(0.4)

* Standard deviation assuming normal distribution.

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water over the entire soil surface, may have contributed to the normal distribution of the initial soil data for the shallow soil layer. At deeper depths, where the ion compositions were influenced by the water uptake pattern, the data were not normally distributed. During the experiment, the irrigation system applied water only under the tree canopies, an area equal to about half of the soil surface, which probably accounted for the skewed distribution near the soil surface. With high frequency irrigation almost 90% of the water uptake occurred above a depth of 0.6 m (See Table 7). Apparently, this water uptake pattern interacted with the non-uniform distribution of water application resulting in normally distributed data below 0.3 m.

Insufficient time elapsed between 1974 and 1979 to achieve truly steady state soil solution compositions at the reduced irrigation rates. The quantity of sodium added to the soil in the irrigation water during the experiment relative to that required to achieve steady state was estimated to be 1.6, 0.9, and 0.5 for the 20, 10, and 5% leaching treatments, respectively. The corresponding values for magnesium are 0.5, 0.3, and 0.2. Figure 9 shows the initial and final R_{Na} distributions with soil depth within the wetted perimeter (0.5-2.0 m), along with the distributions predicted at steady state based on the water uptake distribution within the wetted perimeter given in Table 7. The projected and measured R_{Na} distributions with

TABLE 7. RELATIVE WATER UPTAKE DISTRIBUTIONS BASED ON MEAN SOIL CHLORIDE CONCENTRATIONS IN MARCH 1976 AND 1979 WITH SOIL DEPTH UNDER THE TREE CANOPY FOR THE 5 AND 20% LEACHING TREATMENTS

Soil Depth	5% Leaching Treatment*		20% Leaching Treatment**	
	Soil Chloride Concentration	Relative Water Uptake	Soil Chloride Concentration	Relative Water Uptake
m	mol m^{-3}		mol m^{-3}	
0.25	11.1	0.76 + 0.04 - 0.08	8.4	0.78 + 0.08 - 0.10
0.55	15.4	0.87 + 0.04 - 0.05	9.8	0.87 + 0.08 - 0.09
0.85	20.6	0.94 + 0.02 - 0.04	10.8	0.92 + 0.07 - 0.09
1.15	28.2	0.99 ± 0.02	12.6	0.99 + 0.06 - 0.07
1.45	29.5	1.00	12.8	1.00

* L = 0.13

** L = 0.29

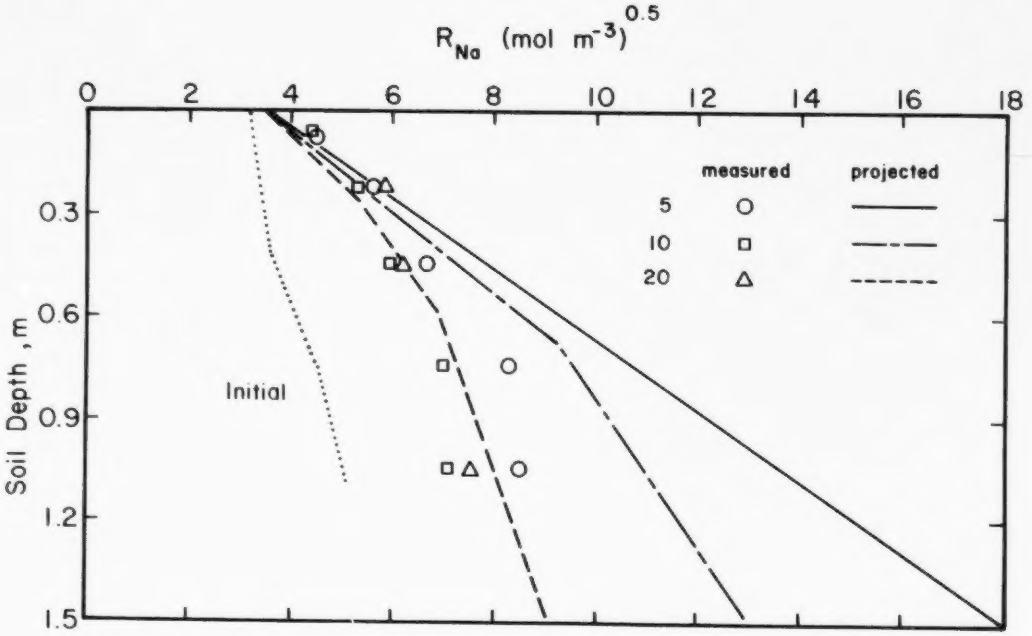

Fig. 9. Distribution of the sodium-adsorption-ratio (R_{Na}) with soil depth at the initiation of the experiment and at its conclusion for the three leaching treatments. Also shown are the projected distributions at steady state which are based on the water uptake distribution measured beneath the tree canopy conditions where one-dimensional flux was assured.

depth for the 20% leaching treatment were in good agreement. Agreement for the 5% and 10% leaching treatments occurred only in the shallow portion of the soil profile because equilibrium was not attained below 0.3 m. Similar analyses for calcium and magnesium were unsuccessful because they were confounded by exchange reactions and lime dissolution. The average magnesium concentrations in the drainage water for the 5 and 10% leaching treatments were only 28 and 46% of the expected steady state values.

Soil Chloride Distribution

The distribution of water uptake from a soil root zone is determined by surface evaporation, root uptake, and leaching fraction. Because chloride does not precipitate and negligible quantities are taken up by plant roots, the fraction of water lost as a function of soil depth can be calculated from knowledge of the leaching fraction (L), the chloride concentration of the irrigation water (Cl_i = 3.7 mol m^{-3}), and the chloride concentration of soil water (Cl_z) at a given depth, z. Thus, the relative water uptake (U) above depth z is

$$U = (1 - Cl_i/Cl_z)/(1 - L). \qquad (2)$$

The factor (1 - L) is the portion of the irrigation water that is lost as evapotranspiration and ($1 - Cl_i/Cl_z$) is the fraction of the irrigation water lost in the root zone above a given soil depth. At the soil depth where $L = Cl_i/Cl_z$, root water uptake has ceased. This analysis is valid only when steady state conditions have been attained, or at least approached.

The soil chloride concentration distributions presented in Fig. 10 reflect treatment differences in water application as well as periods of under- and over-irrigation which ocurred during the course of the experiment. As expected, chloride concentrations are highest in the 5% leaching treatment and lowest in the 20% treatment. Under-irrigation occurred in both 1974 and 1977. As a result, the chloride distributions for these years peaked at a depth of about 0.9 m; and with the exception of the 20% treatment in 1974, the concentrations exceeded those measured at other times. The experiment was over-irrigated during the summer of 1976, and as a consequence, the chloride concentrations measured between October and December of 1976 were low.

The chloride concentrations measured in March 1976 and March 1979 are considered to be the most representative of steady state conditions. They were averaged and then used to calculate the relative water uptake distributions with depth for two of the treatments, as presented in Table 7. The confidence limits (Probability = 0.05) on relative water uptake were calculated from an assumed coefficient of variation of 0.5 and a sample size of 32. The probabilities of these confidence intervals are not exactly 0.05. They were calculated assuming the chloride concentrations were normally distributed whereas they were log normally distributed. However, the confidence intervals calculated on the basis of untransformed and log transformed data

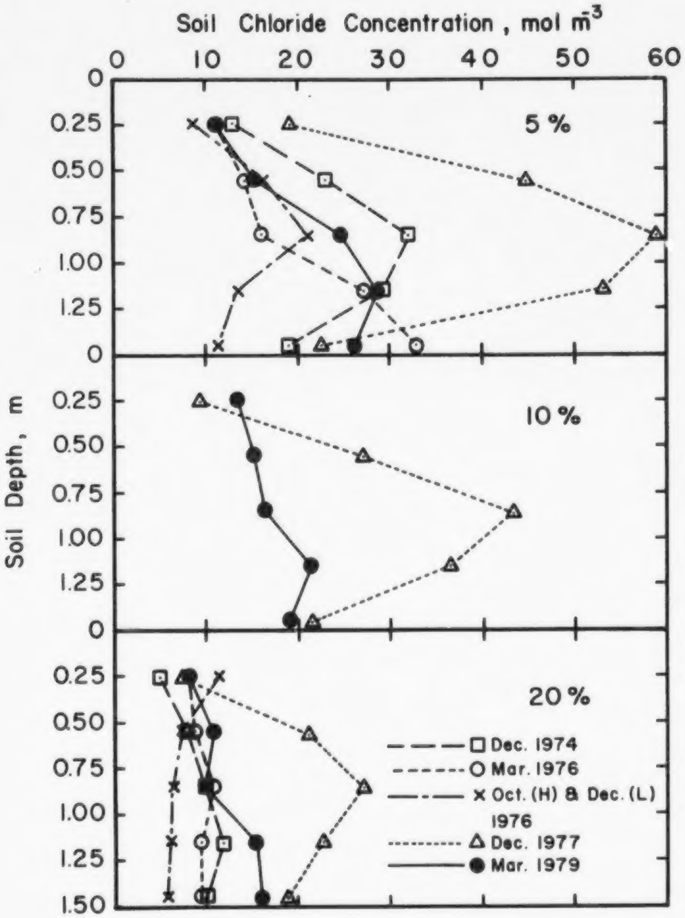

Fig. 10. The concentration of chloride in the soil water beneath the tree canopy during the citrus experiment as a function of soil depth.

(antitransformed) will be quite similar as was demonstrated by Oster and Wood (1977) for irrigation field efficiencies which are also a function of $1-Cl_i/Cl_z$. The water uptake distributions are very similar for both treatments; about 75% of the water is taken up above a depth of 0.25 m and more than 90% above 0.85 m.

The above one-dimensional interpretation of the chloride distributions overlooks much of the variation. Figs. 11 and 12 present chloride distributions at various dates for the 5 and 20% leaching treatments, obtained by compositing the data obtained along three radial lines. An overview of these distributions clearly shows that the highest concentrations in both treatments occurred outside the tree canopy. The chloride concentrations were higher for the treatment with 5% leaching than that with 20%. They increased from 1975 to 1976 for both treatments; it is less obvious whether there was an increase from 1976 to 1979. Significant lateral water movement and water loss beyond the tree canopy must have occurred to create these spatial distributions.

Lateral water movement complicates the use of chloride ratios for evaluating leaching fraction. The depths to the maximum chloride concentrations in Figs. 11 and 12 decrease with increasing distance from the trunk, indicating that the bottom of the root zone is saucer shaped. To estimate a representative average chloride concentration at the bottom of the root zone, a 30-cm thick layer was selected as the approximate root zone boundary (Fig. 13). This layer was divided arbitrarily in three parts and the chloride concentrations of samples taken within these parts were averaged (Table 8). The average chloride concentrations obtained in this manner were then weighted on the basis of the approximate cross-sectional area of each segment through which flow took place. The areas were estimated as a circular section from 0 to 2 m, and as annular sections of radius 2.5 and 3.1 m, respectively.

The weighted mean chloride concentrations obtained in the above manner were 32 and 65 mol m^{-3} for the 20 and 5% leaching treatments, corresponding to leaching fractions of 0.12 and 0.06. Although the results are reasonable, it is recognized the calculations are in error. The weighting should be on the basis of equal amounts (or rates) of water inputs to the system rather than on the basis of equal area of efflux. Data available did not permit the appropriate calculation, but the water content data given in Fig. 9a of Dirksen, Oster and Raats (1979) confirm that there was outward directed lateral flow.

The weighting method used tends to overestimate the mean chloride concentration and thus to underestimate the leaching fraction. A lower limit to the chloride estimate, and thus an upper limit to L, is obtained by assuming no lateral flow. The mean chloride values from the 0- to 2-m section underneath the trees were 12 and 32 mol m^{-3}; the corresponding leaching fractions are 0.31 and 0.12. Thus, one can conclude that for the low leaching treatment $0.06 < L < 0.12$, and for the high leaching treatment $0.12 < L < 0.31$.

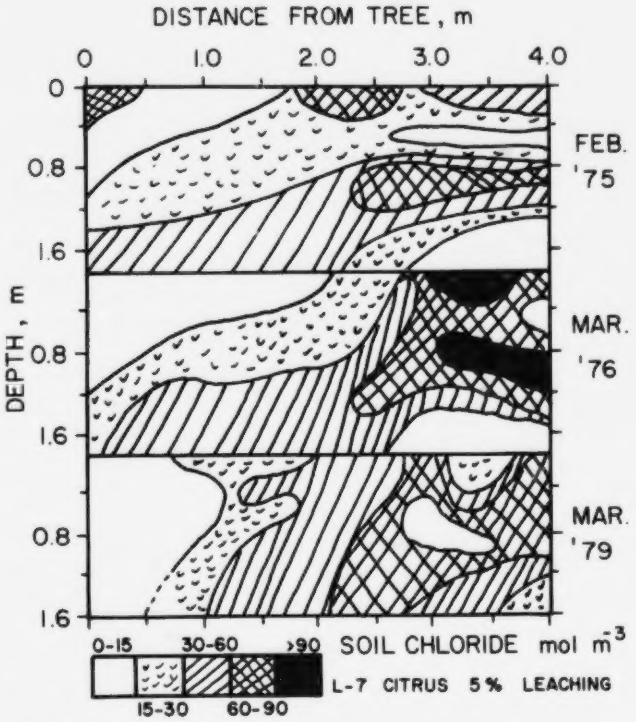

Fig. 11. Distribution of chloride in the soil water under one citrus tree for the 5% leaching treatment at three times during the experiment.

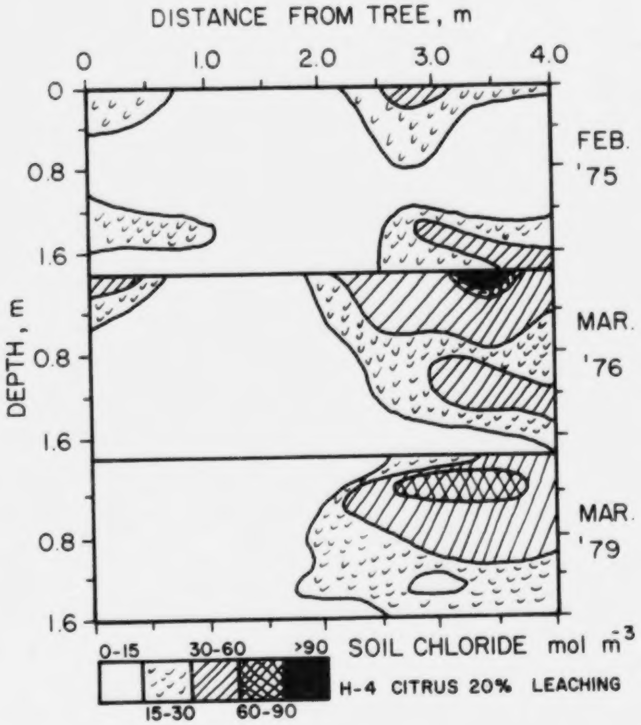

Fig. 12. Distribution of chloride in the soil water under one citrus tree for the 20% leaching treatment at three times during the experiment.

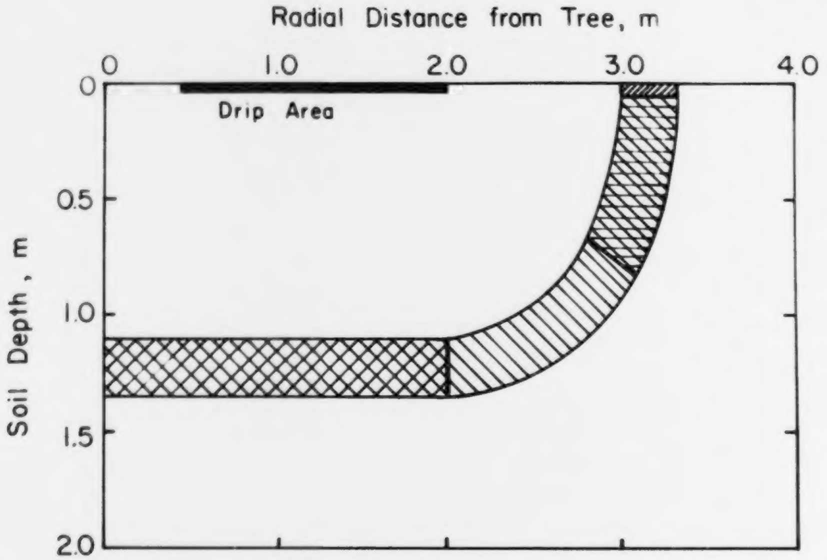
Radial Distance from Tree, m
0
1.0
2.0
3.0
4.0
Drip Area
Soil Depth, m
0
0.5
1.0
1.5
2.0

Fig. 13. Boundaries used to determine which chloride concentrations to use to calculate area-weighted average chloride concentrations.

TABLE 8. SOIL WATER CHLORIDE CONCENTRATIONS (mol m^{-3}) BELOW THE CITRUS ROOT ZONE

Leaching Treatment	Distance from Tree m	Soil Sampling Dates Mar. 1976	Soil Sampling Dates Mar. 1979	Mean	Weighting Factor
20%	0-2	10	14	12	4
	2-2.9	8	16	12	6
	2.9+	75	47	61	7
		Weighted Mean		32	
5%	0-2	33	32	32	4
	2-2.9	59	40	50	6
	2.9+	110	81	96	7
		Weighted Mean		65	

Soil Salinity

The time course of average soil salinity for the three leaching treatments is given in Fig. 14. Not unexpectedly, soil salinity was never steady. The frequency of oscillation, or the time required to undergo one cycle of increasing and decreasing salinity, during 1975 and 1976 (7-10 months) was shorter than that during 1977 and 1978 (17 months). The reduced frequency of oscillation resulted from the change in water management which occurred in January 1977. Prior to this date, water application was controlled by tensiometer; afterward, irrigations were performed manually to maintain cumulative water application as close as possible to a preset fraction of pan evaporation in the citrus grove as explained earlier.

The irrigation factors (see page 22) for the last 2 years of the experiment were based on soil salinity levels at the 0.30- to 0.45-m soil depth. The initial factor of 0.84, used from January to August of 1977, was too low as was evident when soil salinity began to increase rapidly in the summer of 1977. Increasing the factor to 0.95 resulted in a general lowering of salinity beginning in the fall of 1977 for H and M leaching treatments and in the winter of 1978 for the L treatments; the lowering trend ended in the summer of 1978. After that, the soil salinity in the 0.30- and 0.45-m soil depth interval was relatively stable, whereas salinity at deeper depths tended to increase.

The feedback irrigation control system based on salt sensor readings and tensiometers was difficult to manage. We failed to develop a method to predict the change needed in the tensiometer set points to account for the lag in response of soil salinity to changes in irrigation.

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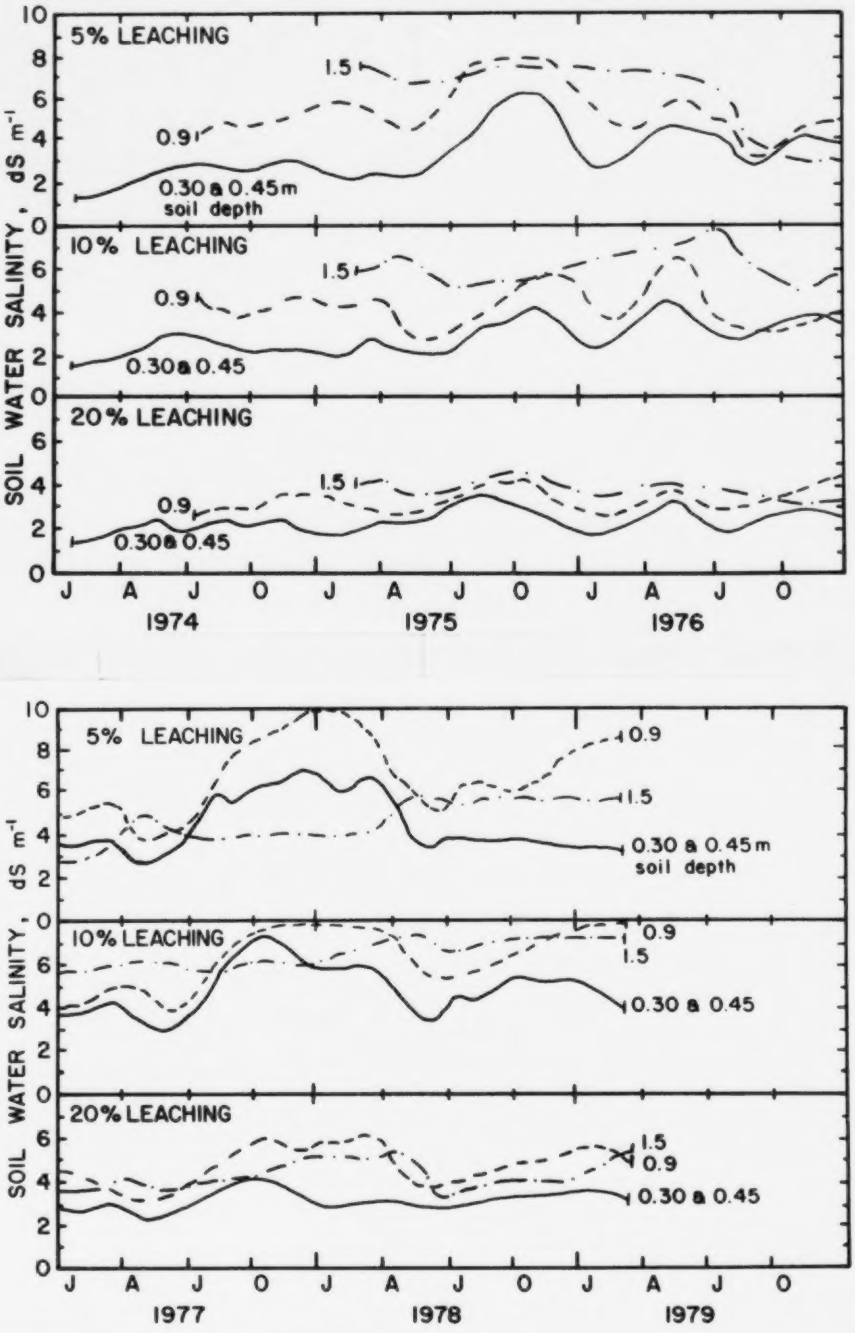

Fig. 14. Soil salinity trends with time for the time for the three leaching treatments of the citrus experiment. Soil water salinity is the average of that measured in the three heavily instrumented replicates of each leaching treatment.

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Travel times for a parcel of water can be calculated approximately as illustrated earlier (See Fig. 16 in U. S. Salinity Laboratory Staff, 1977). For an irrigation rate of 7 mm/day, such calculations indicate a lag time on the order of 2 weeks for movement from the surface to a depth of 0.3 m, with progressively slower movement with increases in depth and corresponding decreases in remaining soil water flow. Observed lag times are of this same order of magnitude. Estimating from data in Fig. 14, travel times between 0.3 and 0.9 m were 2 and 4 weeks for the H and L treatments, respectively; between 0.9 and 1.5 m, they were 5 and 7 weeks. When the rate of irrigation exceeded 7 mm/day (April-Sept), responses were faster; the records show an initial response in soil salinity after 2 weeks, but 3 to 4 weeks elapsed before the response was sufficient for control purposes.

These observations suggest that the shortest period for an oscillation with the tensiometer/salt sensor control system would be around 2 months (2 x 4 weeks). In fact, the shortest cycle in 1976 was 7 months. This longer period no doubt was the result of uncertainty as to how much to change the set point to match the evaporative demand.

The time-averaged soil salinity distributions by year during the experiment are given in Fig. 15. Soil salinities inferred from soil chloride concentrations were in agreement with measured soil salinities at the time soil samples were taken for chloride analysis. The chloride values used to compare the salinity and chloride measurements were averages of 6 to 27 individual samples obtained within the irrigated area; the corresponding numbers for the soil salinity averages were 2 to 12. The regression relationship obtained between salinity (σ) and chloride concentration (Cl) was

$$\sigma = -0.07 + 0.38\ \mathrm{Cl} - 0.0044\ \mathrm{Cl}^2. \qquad (3)$$

A confidence interval was determined by varying the coefficient of the quadratic term ± 0.0017, its standard error. Fig. 16 shows this envelope representing the experimental data, together with the relation between σ and Cl expected on theoretical grounds, taken in effect from Table 3. Thus, Fig. 16 verifies that the Cl and salinity measurements were in agreement.

In view of the above noted agreements, there is a basis for combining information about the spatial distribution of soil chloride concentration with soil salinity data to obtain another estimate of the leaching fraction.

The average annual soil salinities at a depth of 1.5 m from the trees for the 20 and 10% leaching treatments were 4.4 and 6.6 dS m^{-1} over the period 1975 - 1978. These correspond to the chloride concentration in the 0- to 2-m zone (Table 8). Assuming that the same ratio applies to the salt sensor data between weighted mean value and that in the 0- to 2-m region as determined for the chloride data (32/12), the spatially averaged salinities would be 11.7 and 17.6 dS m^{-1}, and the corresponding leaching fractions 0.08 and 0.05, using Table 3.

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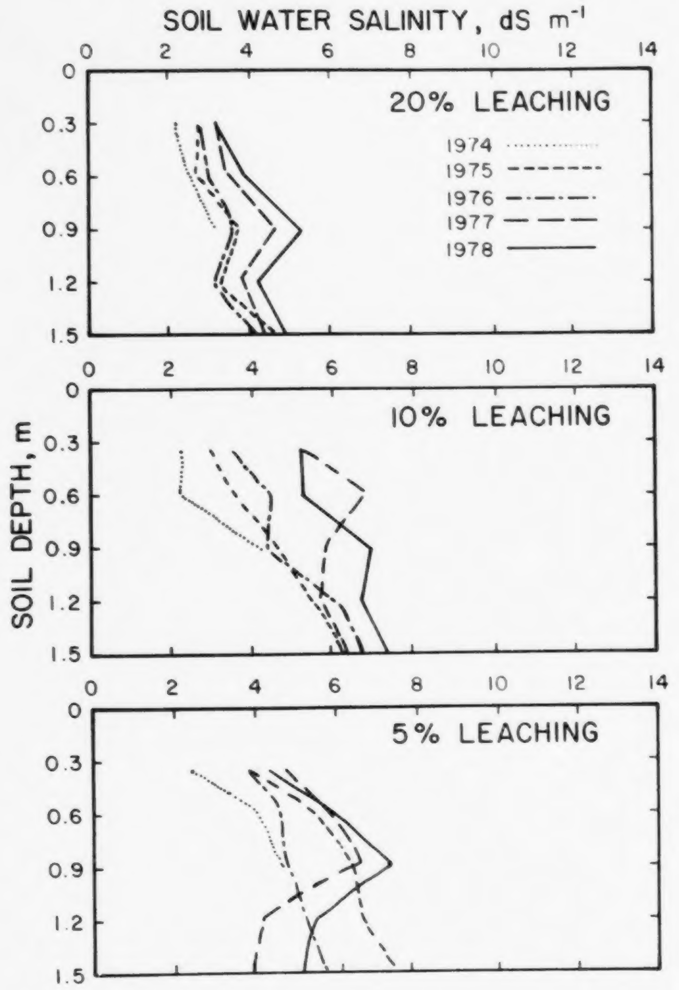

Fig. 15. Time-averaged, soil salinity distributions by year during the citrus experiment.

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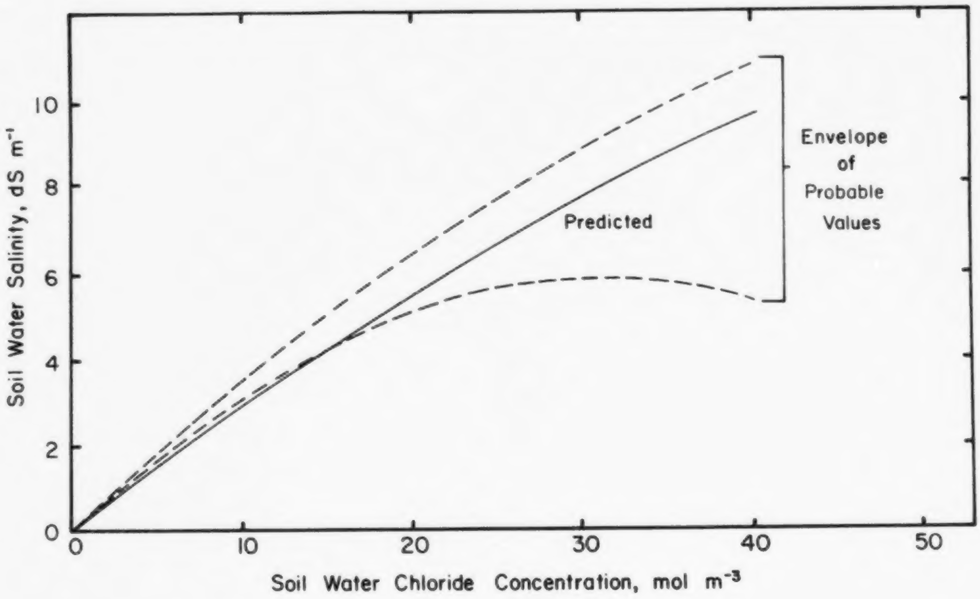

Fig. 16. Comparison of the envelope of experimentally measured and model-predicted relationship between soil water salinity and soil water chloride concentration.

Using the same reasoning as before, these values should be considered lower bounds with the upper bounds determined directly from the 1.5-m deep salt sensor data. Thus we obtain the estimate for the 20% leaching treatment, $0.08 < L < 0.25$; and for the 10% treatment, $0.05 < L < 0.16$.

Data for the 5% leaching treatment were not used because of the peaked distribution of soil salinity with soil depth in 1977 and 1978 (Fig. 15); this type of distribution would suggest upward flow, or negative leaching.

Hydraulic Properties

The relationship between hydraulic conductivity and soil water matric potential for Dateland fine sandy loam soil is given in Fig. 17. These data were obtained from three 0.9-m-deep undisturbed soil columns taken in the fall of 1973. The horizontal lines in the figure indicate the standard error in each measured point.

Soil Hydraulic Head

The 60 tensiometers installed in each of the three leaching treatments were read twice weekly, so that more than 18,000 individual readings were obtained from the three leaching treatments each year. To illustrate the trends among treatments with soil depth and time of year, hydraulic heads, averaged for all tensiometers at a given depth in each leaching treatment over time, were determined for a 3-month period each winter, and a 3-month period each summer. Fig. 18 illustrates how the mean matric potentials, averaged over the 5-year period, varied among the three leaching treatments.

The matric potential is lower (more negative) at all depths during the winter than during the summer, and consistently decreases with depth both winter and summer to a depth of 0.6 m. The lower matric potential during winter is the consequence of the lower water flux through the soil profile necessary to meet the reduced crop water requirement. Because the plots are irrigated frequently, downward water flow approaches steady state. The soil water matric potential therefore decreases in winter and increases in summer as soil water flux changes. The decreasing matric potential with depth simply reflects the fact that the flux is reduced with depth as water is removed by the tree roots. The flux below a depth of 0.6 m is too low to show a consistent downward potential gradient.

The variation of the soil water matric potential gradient with time is illustrated in Fig. 19 for the 10% leaching treatment. During periods when reduced irrigation caused the upper soil profile to dry out, the matric potential gradient at the lower depths was upward, indicating water was flowing upward from storage at the lower depths to meet the deficit. Readings for the 20% leaching treatment indicate few periods when upward gradients occurred. Soil water matric potentials were generally lower than -20 kPa when the matric potential gradients were upward or zero. At these matric potentials the hydraulic conductivity is less than 1.0 mm day^{-1} [Fig. 17], and water movement--either downward or upward--is small. Consequently,

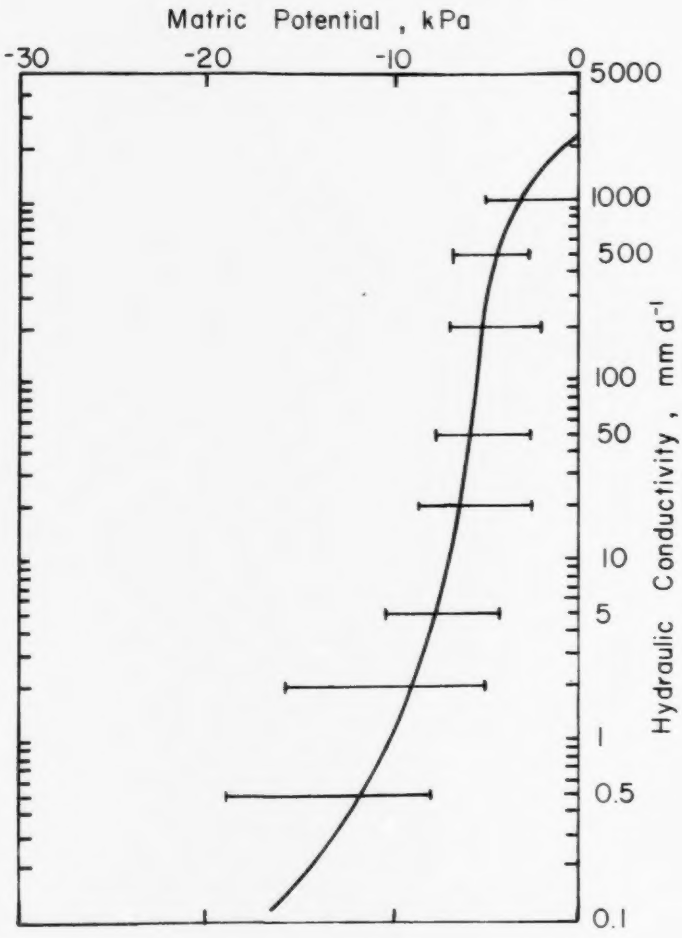

Fig. 17. Relationship between soil water pressure head and hydraulic conductivity for Dateland fine sandy loam soil.

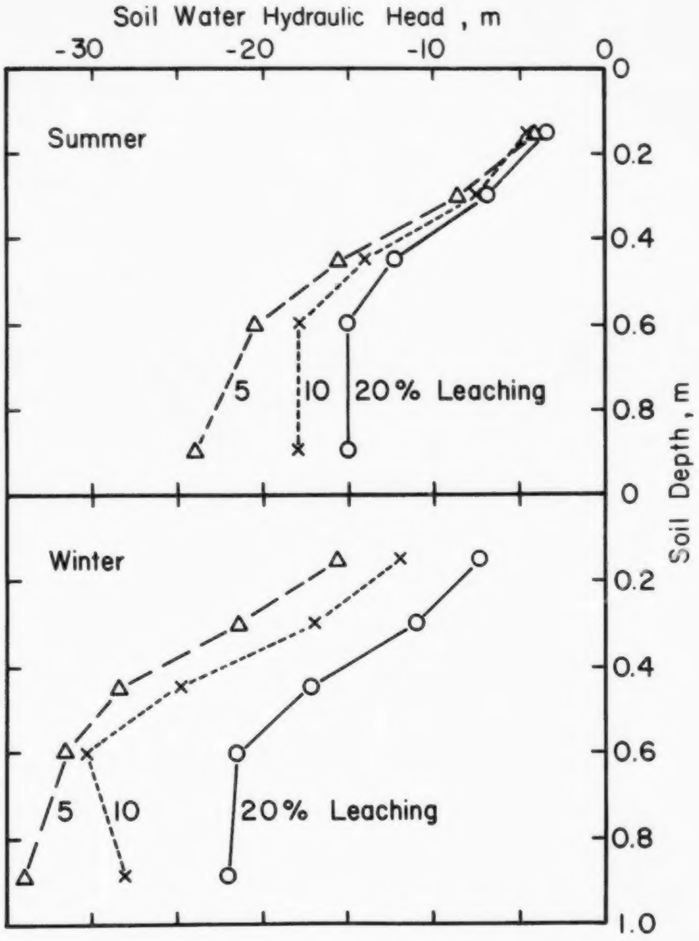

Fig. 18. Average soil water pressure head profiles for 5, 10, and 20% leaching during the summer and winter for the citrus experiment.

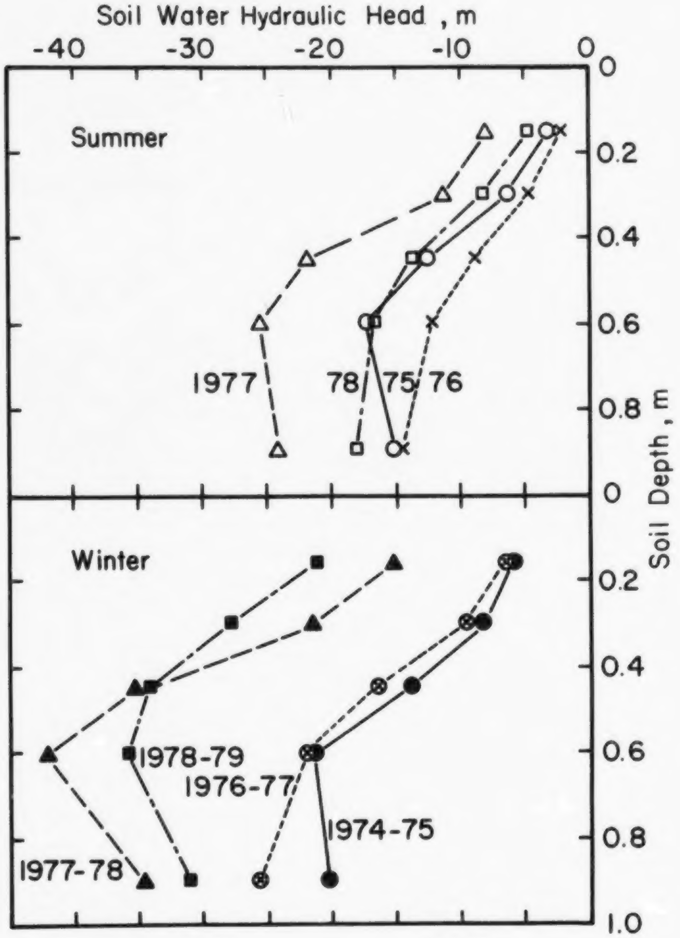

Fig. 19. Variation of soil water pressure head with soil depth for 10% leaching throughout the citrus experiment for the summer and winter.

the water applied approximately equaled that evapotranspired and provides a measure of the irrigation factor (Table 9). The average irrigation factors based on total water applied for those treatments with upward hydraulic head gradients for the pan located in the grove are 1.31 for winter (Nov.-Jan.) and 1.00 for summer (June - Aug); the corresponding numbers for the Mesa pan are 0.38 and 0.70. Using these measured k_i values for the Mesa pan in the winter and summer months and assuming the k_i value for the months of February, March, April, May, September and October is 0.54, the average of 0.38 and 0.70, the calculated ET for citrus is 1470 mm. These k_i values agree favorably with the k_i values used to calculated ET based on published values of k_c (given in Table A-5) and a value of 0.7 for k_p ($k_i = k_c k_p$). Using the published values of k_c results in an annual ET of 1450 mm (see Table 11). Based on the average annual depths of water (Table 10) and an ET of 1470 mm, the leaching percentages for the 5, 10, and 20% leaching treatments were 5.2, 9.8, and 21.0%, respectively.

Pan Evaporation

Pan evaporation for two locations in southwest Arizona is summarized in the Appendix. Both pans were the standard Class A Weather Bureau type. The data in Table A-3 are for a pan located about 0.5 km north of the experiment within the Valencia orange grove in place of a tree. The data in Table A-4 are for a pan located at the Mesa Experiment Station of the University of Arizona near Yuma, about 70 km west of the experiment. The annual rate of evaporation from the pan within the grove was 1670 mm while the annual rate for the Mesa Station pan was 2520 mm. The average daily pan evaporation rate in the grove was about 70% of the open area pan at the Mesa Station except in the winter months when it dropped to as low as 20%. These pan evaporation measurements may seem at variance with the data discussed in the foregoing section. The nature of these agreements and discrepancies will be addressed in the Water Use section.

Water Use

The average daily water application for the three leaching treatments is given in Fig. 20 by months for the period of February 1974 to December 1979. For the flood check the time interval is from January 1975 to December 1979. These water applications were the sum of irrigation and rainfall and were calculated for the total area allocated each tree, 32.7 m^2. The average volume applied daily to each tree in liters is 32.7 times the depth given in Fig. 20. The average daily applications applied to each treatment for each month of the experiment are given in Fig. A-1 of the Appendix.

The annual water applications for the three leaching treatments are given in Table 10, along with those for the two borders and the flood check plot. As planned, the two borders received about the same amount of water as the 20% leaching treatment. The flood check, irrigated by the ranch, annually received about 900 mm more than the 20% leaching treatment. Rainfall, totalled per month, is given in Table A-2 for the 5-year period of the experiment. The mean annual rainfall was 116 mm, more or less evenly

TABLE 9. IRRIGATION FACTOR, k_1, BASED ON AMOUNT OF APPLIED WATER DURING THREE MONTH TIME INTERVALS WHEN THE AVERAGE MATRIC POTENTIAL GRADIENTS IN ONE OR MORE TREATMENTS WERE NEGATIVE. IN THESE EXAMPLES k_1 = I/E BECAUSE L IS ASSUMED TO BE ZERO

Time Interval	Ave. Application			Pan Evap.		Irrigation Factors					
						Grove			Mesa		
	5%	10%	20%	Grove	Mesa	5%	10%	20%	5%	10%	20%
	----------mm day^{-1}	-----------									
				Winter (Nov-Jan)							
74-75	1.15*	1.15	1.48*	1.2	3.4	0.96*	0.96	1.23*	0.34*	0.34	0.44*
77-78	1.14	1.26*	1.28*	0.8	3.1	1.42	1.58*	1.60*	0.37	0.41*	0.41*
78-79	0.95*	1.03*	1.25	0.8	2.9	1.19*	1.29*	1.56	0.33*	0.36*	0.43
						avg 1.31 (1.31)*			avg 0.38 (0.38)*		
				Summer (June-Aug)							
75	7.53	6.97*	8.57	8.1	10.8	0.93	0.87*	1.06	0.70	0.65*	0.79
77	7.65	7.70*	8.18*	7.5	10.9	1.02	1.03*	1.09*	0.70	0.71*	0.75*
						avg 1.00 (1.00)*			avg 0.72 (0.70)*		

* Treatments with negative matric potential gradients.

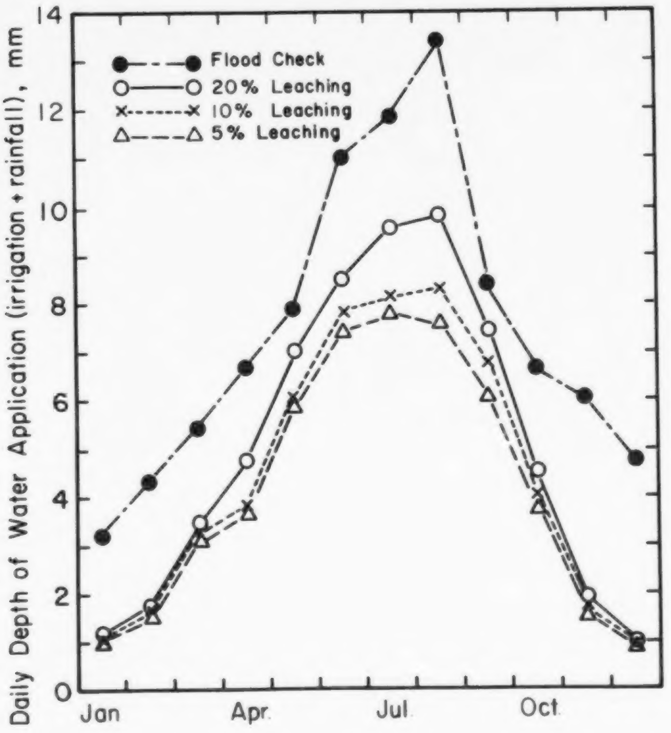

Fig. 20. Average daily water application by month for the three leaching treatments and the flood checks in the citrus experiment.

distributed among the months except for a lack of rainfall in May and June.

Water was withheld initially to increase soil salinity to the projected levels for the three leaching treatments; thus the total applied in 1974 is below the mean (see Fig. A-1 and Table 10). In contrast, in the summer of 1976, a series of high water applications took place inadvertently.

Evapotranspiration (ET) was calculated as 95, 90 and 80% of the total amount (irrigation plus rainfall) applied for the 5, 10 and 20% leaching treatments, respectively. ET should be the difference between the amount of water applied and the amount of leachate draining below the root zone. No extraneous surface water entered or left the experimental area and no water table was found within 5 m of the soil surface during the duration of the experiment. Any change in soil water storage during the long experiment was minute compared to evapotranspiration and can safely be ignored. The soil measurements including salinity, chloride concentrations and soil water matric potential, indicate the achieved leaching fractions were approximately equal(± ~ 5%) to those desired. ET was assumed to be independent of the leaching treatment imposed because data presented below indicate no significant differences in trunk growth among the leaching treatments.

The mean values for evapotranspiration as calculated from the data given in Fig. 20 for each leaching treatment are presented in Fig. 21 as "measured" evapotranspiration. The standard deviation of the monthly means for the three leaching treatments was less than 6% of the means for each month.

As a check on ET independent of the estimate based on water applied, evapotranspiration was also calculated from five equations which use different meteorologic data. The application procedures for four of these equations--pan evaporation, Blaney-Criddle, radiation, and modified Penman--were taken directly from Doorenbos and Pruitt (1975). The procedure for the

TABLE 10. ANNUAL DEPTHS OF WATER APPLIED (mm OF IRRIGATION PLUS RAINFALL) FOR EACH TREATMENT OF THE CITRUS EXPERIMENT

	Leaching Treatment			Borders		Flood Check
	5%	10%	20%	Bubbler	Drip	
1974	1400	1450	1680	1650	1820	---
1975	1500	1560	1800	1940	1910	2650
1976	1730	1830	2090	2200	1910	2990
1977	1570	1650	1850	1880	1700	2750
1978	1640	1730	1940	1930	1990	2690
MEAN	1550	1630	1860	1920	1870	2760

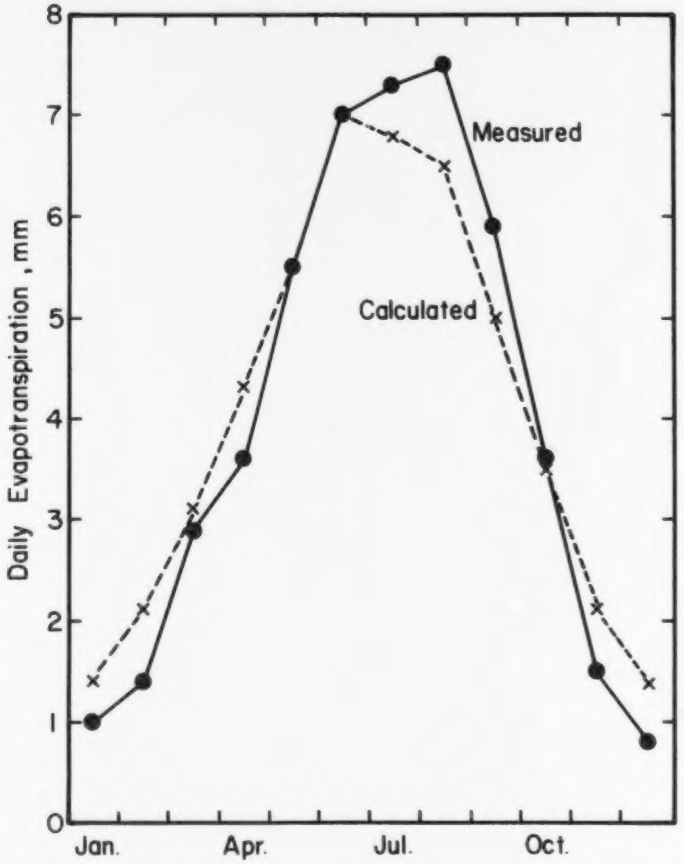

Fig. 21. Evapotranspiration computed from measured water applications and desired leaching fractions (measured) and calculated from various predictive equations (calculated) for mature Valencia orange trees.

Jensen-Haise equation was taken from Jensen (1973). Coefficients and the average meteorological data by month that are required for the various equations are given in Table A-5. The equations are described briefly in order of their increasing complexity.

Pan Evaporation. Evapotranspiration (ET) can be calculated from

$$ET = k_c\, k_p\, E_p = k_i\, E_p \qquad (4)$$

where k_c is the crop coefficient, k_p is the pan coefficient, and E is pan evaporation. The average daily rate of evaporation from a Class A pan on a monthly basis from 1974 through 1978 for the Yuma Mesa Experiment Station and the appropriate values of k_c are given in Table A-5. The pan coefficient based upon the wind, humidity, and pan location at the station was taken as 0.7.

Radiation. Using primarily solar radiation data, evapotranspiration can be calculated from

$$ET = k_c(-0.3 + 0.84\, W\, R_s) \qquad (5)$$

where W is a weighting factor which depends on temperature and altitude and R_s is solar radiation converted to an equivalent depth of evaporation in mm per day. The numerical coefficients are based upon low mean relative humidity and light daytime wind.

Jensen-Haise. Evapotranspiration can be estimated from

$$ET = k_c\, C_T(T-T_x)\, R_s \qquad (6)$$

where C_T and T_x are coefficients which depend on humidity, temperature, and elevation. For this study C_T was 0.0223 and T_x was -3.4°C. T is the mean of the daily maximum and minimum temperatures.

Blaney-Criddle. The original Blaney-Criddle approach estimated consumptive use (f) by the relationship

$$f = p(0.46\, T + 8.13) \qquad (7)$$

where p is the mean daily percentage of annual daytime hours for a given month and latitude. Doorenbos and Pruitt (1975) recommended that ET be calculated from f by

$$ET = k_c(-2.60 + 1.55\ f) \qquad (8)$$

to correct for low daytime humidity, light daytime wind, and a high ratio of actual to maximum possible sunshine hours.

Modified Penman. The original Penman equation to predict the loss of water by evaporation from an open water source has been modified by a revised wind function term, plus a correction for differences in day-night weather conditions (k_w). The modified equation is

$$ET = k_c\ k_w[W\ R_n + (1-W)\ f(u)\ (e_o-e)] \qquad (9)$$

where net radiation (R_n) is R_s reduced by the amount of net longwave radiation, f(u) is the wind-related function, and (e_o - e) is the difference between the saturation and actual vapor pressures at T.

Table 11 gives the calculated evapotranspiration for each of the predictive equations by month based upon the data given in Table A-5. The calculated values are basically in agreement, although on an annual basis the radiation method is low by about 100 mm and the modified Penman equation is high by about 200 mm. The monthly means of the calculated values are given in the last column of Table 11 for comparison with the measured values. This comparison is shown graphically in Fig. 21.

All the equations predict an evapotranspiration rate higher than the measured values during the winter and, except for the modified Penman equation, lower in the summer. On an annual basis, the mean calculated evapotranspiration is in excellent agreement with the annual measured value of 1470 mm or about 50 m^3 per tree. The peak daily rate, averaged over a month, is 7.5 mm or about 250 ℓ per tree.

These data are in excess of the values reported by Erie et al. (1965) who reported an annual evapotranspiration of 990 mm and a peak daily rate of 4.6 mm. Likewise, if the k_c values recommended by MacGillivray (1975), 0.45 to 0.50, are applied, the resulting ET would be far less than the values reported here where k_c values of 0.75 to 0.85 agree well with measured values.

The average ET is compared to the average daily rate of pan evaporation for the pan located within the grove (Table A-3) and for the pan at the Mesa Experiment Station near Yuma (Table A-4) in Fig. 22. As expected, the shape of the curves are similar, but the calculated ET lags pan evaporation throughout. This lag is caused by the slow "feedback" in the irrigation management scheme. During the last 2 years of the experiment with irrigation management controlled primarily by pan evaporation, calculated ET was, of course, in phase with evaporation. The average for the experiment, however, was dominated by tensiometer and salt sensor control.

Based on these data (see also p. 56) the annual irrigation factor (k_i)

TABLE 11. DAILY EVAPOTRANSPIRATION (mm) OF MATURE VALENCIA ORANGE TREES IN SOUTHWEST ARIZONA BASED UPON WATER APPLIED COMPARED WITH CALCULATED VALUES FROM FIVE PREDICTIVE EQUATIONS

Month	Water Applied Divided by One Minus the Leaching Fraction	PREDICTIVE EQUATIONS					Mean of Calculated Values
		Pan Evaporation	Radiation	Jensen-Haise	Blaney-Criddle	Modified Penman	
Jan	1.0	1.5	1.4	1.1	1.7	1.4	1.4
Feb	1.4	2.1	2.1	1.7	2.1	2.3	2.1
Mar	2.9	3.0	3.1	2.7	3.0	3.6	3.1
Apr	3.6	4.3	4.4	4.0	3.9	5.1	4.3
May	5.5	5.3	5.3	5.4	5.1	6.4	5.5
June	7.0	6.8	6.2	7.1	6.7	8.2	7.0
July	7.3	6.7	5.7	6.9	7.0	7.8	6.8
Aug	7.5	6.1	5.6	6.7	6.6	7.4	6.5
Sep	5.9	4.8	4.3	4.9	5.5	5.3	5.0
Oct	3.6	3.3	3.2	3.3	4.1	3.7	3.5
Nov	1.5	2.2	2.0	1.7	2.3	2.0	2.1
Dec	0.8	1.6	1.3	1.0	1.6	1.3	1.4
Annual (mm)	1470	1450	1360	1420	1520	1660	1480

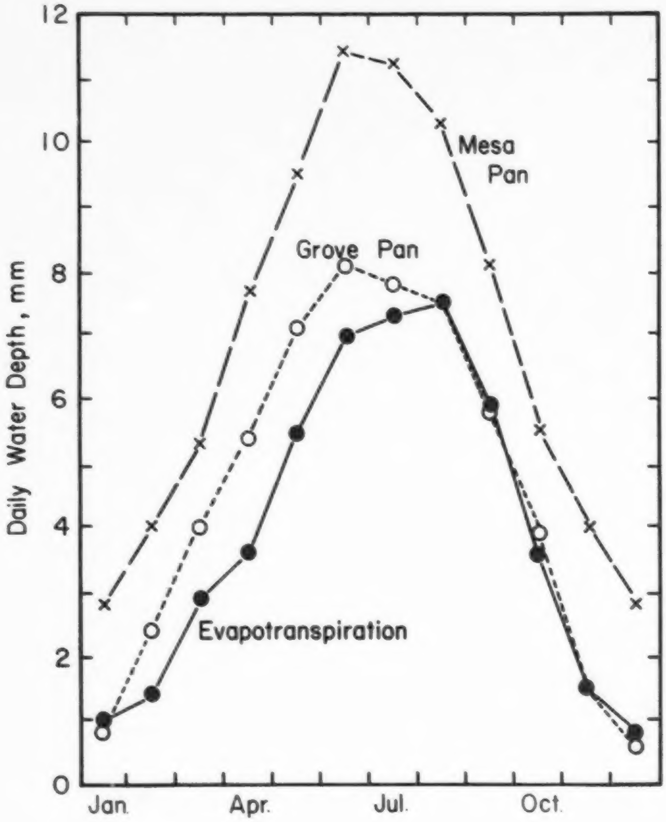

Fig. 22. Comparison of evapotranspiration for the citrus experiment with evaporation from Class A pans within the citrus grove and at the Yuma Mesa Experiment Station.

was 0.88 for the pan located in the grove and 0.58 for the pan on the Mesa Station. The average irrigation factor for the grove pan was 0.94 during the summer (June, July, and August) and 1.20 during the winter (November, December and January). The average seasonal irrigation factors for the Mesa pan were 0.67 and 0.34, respectively. Thus, we have reported that annual evapotranspiration from the trees is close to 1470 mm; and that the annual k_i value for the grove pan is near 0.88 and for the Mesa pan close to 0.58. We are confident that these values are reasonably accurate and defensible.

We have also reported, based on short-term, "steady state" data (Table 9), that the k_i value for the grove pan was 1.31 in winter and 1.00 in summer, while for the Mesa pan the values were 0.38 and 0.72; taking the whole period of measurement into account, the values were 1.20 (winter) and 0.94 (summer) for the grove pan, and 0.34 (winter) and 0.67 (summer) for the Mesa pan. Some of these numbers are highly unreliable (and physically inconsistent). In particular, the k_i values for the grove pan in winter are suspect. However, these discrepancies do not affect the usefulness of the data significantly.

Two observations are pertinent. In winter, the evaporation rates are very low; small changes in measurements (or actual rates) can have large effects on k_i, but they do not greatly affect annual water use, either from a pan or from the trees. Even if winter estimates are off, annual estimates can be sound.

Secondly, the "measured" ET, as calculated from the data, incorporates a certain amount of time lag due to soil water storage, a parameter that was not measured. Figs. 21 and 22 illustrate this lag. A more realistic and correct picture would emerge where the measured ET curve advances in time an appropriate amount. The time of advance needed is probably on the order of 2 weeks. Since no rational way occurred to us for making such an adjustment, none was made. However, the recognition of this lag, together with the minor impact of any errors in the low winter rates, enforce confidence in the accuracy of the long-term averages and minimize concern with the apparent discrepancies.

Vacuum Extractor Volumes and Salt Concentrations

Figures 23, A-2 and A-3 summarize the data obtained from the vacuum extractors installed in treatments M8, H6, and L7. The letters NW, NE, SE, and SW in the legends represent radial direction from the centrally located manhole of each set of extractors toward the adjacent trees. The numbers 1, 2, and 3 represent the individual extractor segments, beginning at the tree and extending toward the manhole. The three curves in each subfigure labelled with symbols show the cumulative volume of solution collected from each extractor with time. The curve without symbols gives the average head (m of water) at the beginning of each month for the four tensiometers positioned over each extractor radial. The three columns of numbers in each subfigure indicate the chloride concentration in mol m^{-3} of solution from extractor segments 1, 2, and 3 (from top to bottom), on the dates indicated

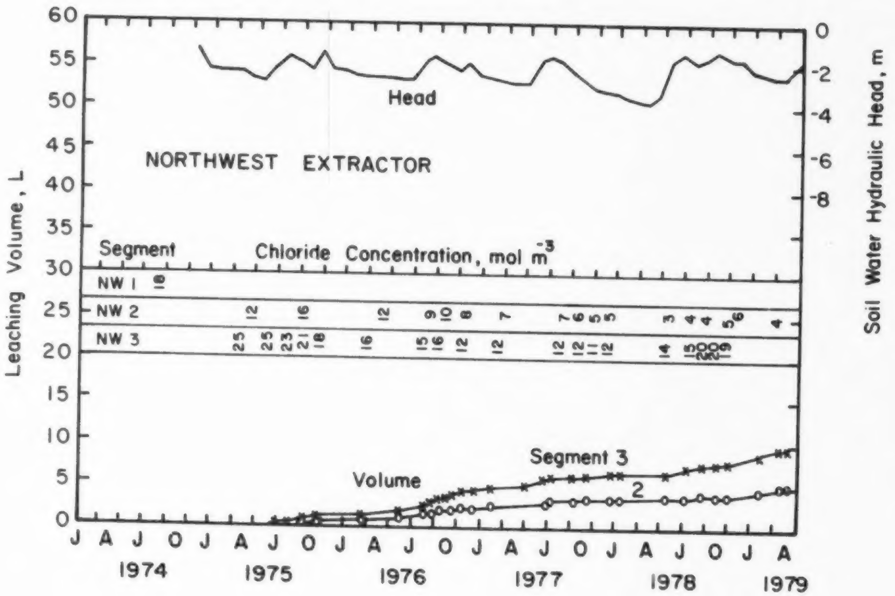

Fig. 23a. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot M8 (refer to Fig. 2 for exact location).

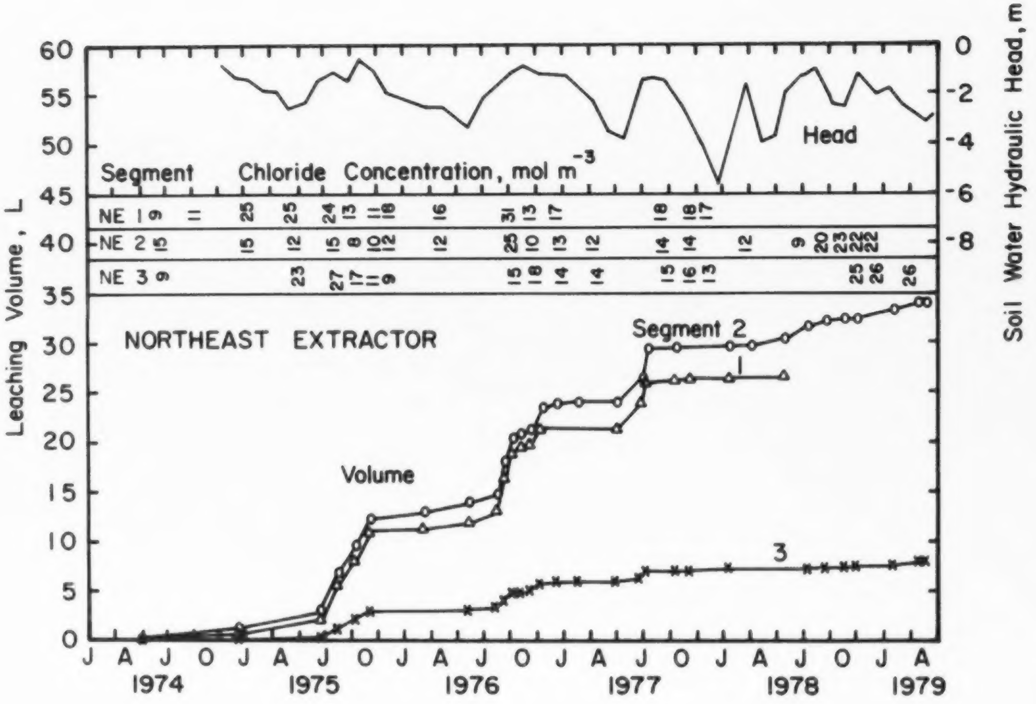

Fig. 23b. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for the northeast extractor in plot M8.

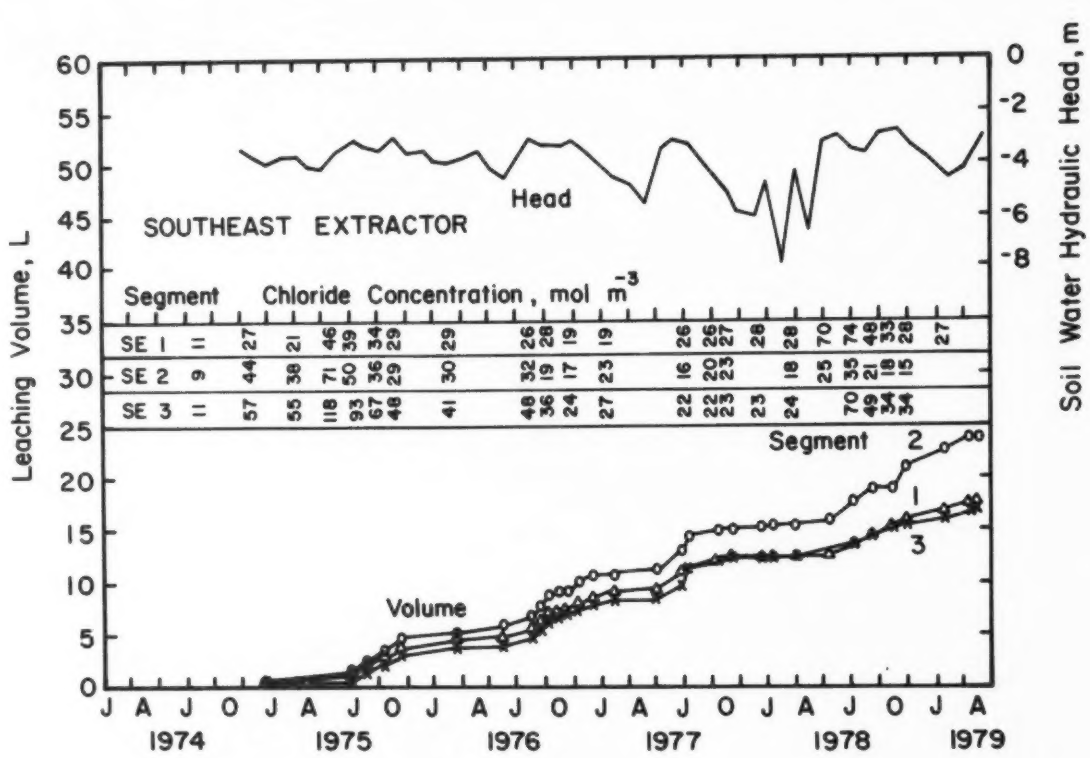

Fig. 23c. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for the southwest extractor in plot M8.

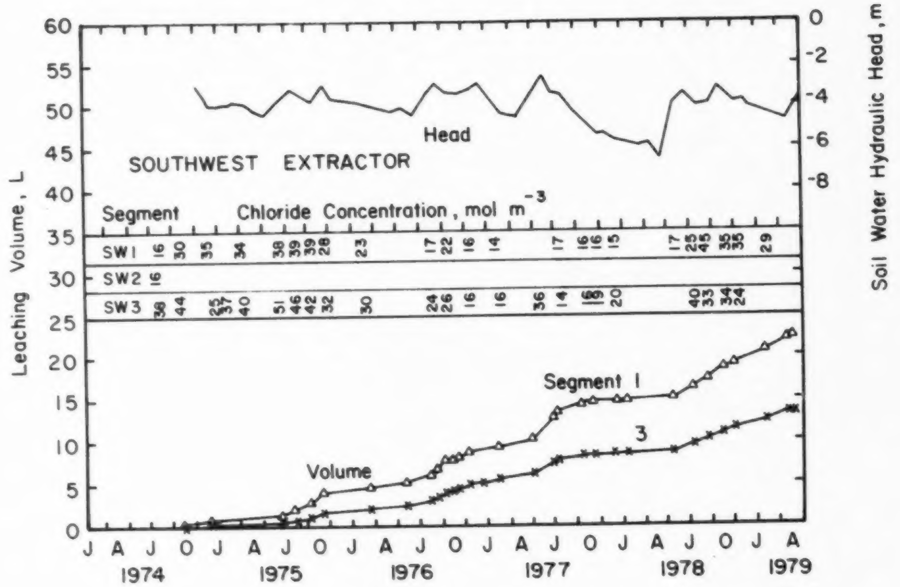

Fig. 23d. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for the southeast extractor in plot M8.

by the position of the numbers.

If the vacuum extractors accurately intercept a quantity of leachate proportional to their horizontal area, the leaching fraction can be calculated as the ratio of that volume to the volume of irrigation water applied to the same area at the soil surface. Likewise, if the concentration of the solution collected in the extractor sample bottles accurately represents that of the soil solution at the same elevation, the leaching fraction can be calculated as the ratio of the chloride concentration in the irrigation water to that collected by the extractor. This calculation assumes that (1) chloride does not react within the soil but is simply concentrated as water is selectively removed through roots in response to transpiration demand, (2) that steady state exists; and (3) that the vacuum extractors are located below the depth of water uptake by roots.

In general, the accumulative leaching volumes do not correspond to those expected on the basis of leaching fraction treatment. The highest accumulative volume was obtained from the extractors on the SW radial in treatment L7. Also, the volume extracted from individual segments of extractors on the same radial varied widely, as for example in the NE radial of extractor M8. If this variation in leaching volumes was caused by differences in leaching fraction in the soil, an inverse relationship between leaching volume and chloride concentration should have been found. No such relationship exists for extractor M8, or for any other extractor radial, with the possible exception of the extractor on the SE radial of treatment L7.

The soil water matric potential above the extractors generally had to exceed about -20 kPa before any solution was extracted, but the correlation between volume extracted and matric potential is poor. Following the reinstallation of the extractors in H6 and L7 in 1977, the volume of solution collected did seem to increase even though the matric potential was not noticeably higher. In all cases, the major part of the solution was collected between the 6th and 12th months each year -- corresponding to the period following the greatest water applications.

Table 12 summarizes the average leaching fraction by year for each radial of the three extractor installations calculated from (1) the volume of leachate collected by the vacuum extractors, and (2) the volume weighted mean chloride concentration of the leachate samples. The leaching fractions calculated from leachate volumes are about an order of magnitude less than those calculated from chloride concentrations. This indicates that the volume of solution removed by the extractors was less than that moving through an equivalent area in the soil, suggesting the presence of a high resistance to water flow across the boundary between the disturbed soil in the extractor and the undisturbed soil above. Reinstallation of the extractors in plots L7 and H6 in 1977 did improve their operation, as is indicated by the significantly higher leaching fractions based on volume of leachate for all but one of the extractors in these treatments during 1978. After reinstallation, radials SE in H6 and SW in L7 continued to show the

TABLE 12. AVERAGE LEACHING FRACTIONS FOR THE THREE SEGMENTS OF EACH RADIAL IN THE THREE LEACHING TREATMENTS OF THE CITRUS EXPERIMENT

	Volume of Leachate				Chloride Concentration of Leachate			
Radial Year	NW	NE	SE	SW	NW	NE	SE	SW
				5% Leaching Treatment, Plot L7				
1975	---	---	---	0.022	--	--	0.09	0.11
1976	---	0.015	0.017	0.086	--	0.04	0.09	0.19
1977*	---	0.002	0.000	0.046	--	0.10	0.17	0.16
1978	0.012	0.012	0.042	0.131	0.27	0.08	0.10	0.21
				10% Leaching Treatment, Plot M8				
1975	0.004	0.054	0.024	0.011	0.19	0.25	0.07	0.10
1976	0.011	0.053	0.035	0.020	0.30	0.23	0.14	0.18
1977	0.006	0.034	0.029	0.020	0.40	0.15	0.17	0.21
1978	0.007	0.010	0.035	0.033	0.27	0.20	0.11	0.13
				20% Leaching Treatment, Plot H6				
1975	0.002	0.010	0.049	0.013	0.30	0.18	0.33	0.25
1976	0.003	0.011	0.026	0.015	0.28	0.29	0.34	0.41
1977*	0.001	0.009	0.015	0.011	0.26	0.17	0.16	0.16
1978	0.042	0.029	0.064	0.031	0.15	0.23	0.23	0.24

*Extractors reinstalled between January and June 1977.

highest leaching fraction. This could have resulted from differences in soil texture and corresponding differences in contact resistance, or it could represent an actual difference in soil water flux rates. The fact that the leaching fractions even in the radials with the highest rate were still below those indicated by the chloride concentration of the leachate suggests that reinstallation did not solve the problem. We can only conclude that even with extreme care to avoid a contact resistance at the extractor interface, water apparently flowed around the vacuum extractors. The extremely low hydraulic gradients in the vicinity of the extractor made it impractical to precisely balance the pressure head but changes in resistance probably were far more important than variations in gradient. Vacuum extractors in this instance were not capable of accurately measuring downward flux of soil water.

As samplers of the soil solution, however, the vacuum extractors apparently performed better. The average leaching fractions by treatment based on chloride concentration are highest for the high leaching treatment and lowest for the low leaching treatment. The average leaching fractions, calculated from the chloride concentration, were 13, 19, and 25% for the 5, 10 and 20% treatments (Table 12). The large volume of soil within the extractor, however, constitutes a dead volume that introduces a time lag in the sampling. This is particularly serious, as is the case here, where the extractor does not remove a representative volume of downward flowing water. The time lag then depends not only on the dead volume, but also on the flux rate. If the volumetric water content of the soil within the extractor is approximately 0.20 $m^3 m^{-3}$, the quantity of water held in the 18 liters of soil contained within each extractor segment is of the order of 3 liters. From the volumes of leachate shown in Figure 23, A-2 and A-3, it is apparent that there were periods when one pore volume did not pass through the extractor in a year. If vacuum extractors are to be used solely as soil solution samplers, they should be redesigned to reduce their volume to avoid this time lag.

The mean chemical compositions of the leachates are given in Table 13 by year for each leaching treatment. The data show that ionic concentration of the drainage waters increased with time (the initial concentrations were low due to high leaching fractions under past management), and reflect differences in leaching treatment. As expected, ion concentration, σ, and R_{Na} decreased as the leaching fraction increased at the end of the experiment. However, the compositions were still not equal to those expected for steady state. Compared to the expected compositions (Table 3) the leachate waters in 1978 were high in calcium and low in magnesium, sodium, sulphate, and R_{Na}. This is the consequence of the fact that magnesium and sodium continued to be adsorbed by the exchange complex, displacing calcium into the solution. Thus the increases in salt concentration with time in the leachate waters from the extractors are reasonable, reflecting the change from the high leaching fractions of past management and inadequate amounts of sodium and magnesium applied in the irrigation water to achieve steady state ionic composition to a depth of 1.2 m.

TABLE 13. AVERAGE COMPOSITIONS OF THE LEACHATE WATERS FROM THE VACUUM EXTRACTORS FOR THE CITRUS EXPERIMENT BY YEAR

Year	n*	σ	R_{Na}	pH	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
		$dS\ m^{-1}$	$(mol\ m^{-3})^{1/2}$		$mol\ m^{-3}$							
5% Leaching Treatment, Plot L7												
1974	7	4.1	4.7	7.4	9.9	4.4	18.1	0.3	6.7	10.7	18.6	1.0
1975	16	5.8	5.7	7.3	17.1	6.4	27.0	0.4	4.9	17.8	33.7	1.1
1976	27	7.4	7.4	7.1	20.4	8.8	36.0	0.4	6.8	23.4	39.9	1.5
1977	18	5.9	7.2	7.2	13.8	6.2	31.0	0.3	5.0	18.7	27.4	1.9
1978	49	6.8	9.4	7.5	14.6	8.0	35.4	0.4	6.6	19.6	34.7	1.0
1975 to 1978 MEAN											33.9	
10% Leaching Treatment, Plot M8												
1974	21	5.0	5.6	7.6	11.6	5.9	23.7	0.4	7.3	13.2	23.8	1.2
1975	47	6.2	6.1	7.1	17.2	8.5	30.7	0.5	7.3	20.8	32.7	1.8
1976	48	5.6	7.8	7.3	12.0	6.6	33.0	0.4	8.5	20.8	19.8	0.6
1977	36	5.1	9.0	7.4	9.0	5.2	32.0	0.4	6.9	18.0	17.1	1.3
1978	48	5.9	9.0	7.6	11.1	6.2	35.4	0.4	7.3	18.2	26.4	0.6
1975 to 1978 MEAN											24.0	
20% Leaching Treatment, Plot H6												
1974	28	4.2	5.2	7.3	9.8	4.9	20.6	0.3	6.8	12.6	15.0	3.6
1975	51	4.1	4.6	7.2	11.5	5.2	18.3	0.3	6.7	13.9	15.5	2.1
1976	37	3.6	6.0	7.4	8.4	3.8	19.4	0.3	8.5	12.2	11.2	0.7
1977	31	5.5	7.4	7.3	11.2	6.3	29.5	0.6	4.8	18.0	22.4	3.3
1978	67	5.2	7.0	7.6	10.8	6.6	28.3	0.3	7.7	19.0	18.1	0.7
1975 to 1978 MEAN											16.8	

*Number of samples.

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Root Distribution

Leaching treatment, irrigation method and distance from the tree affected total root length (Table 14) in the 0-1.2 depth interval. All treatment averages were significantly different. Average root lengths for the trickle irrigated treatments were about twice those for the flood check. For the latter, distance from tree had no effect on root length, whereas the root density decreased drastically in the trickle irrigated treatments beyond the wetted area which had a radius of about 2.0 m. It is likely that the greater root length at 1.5 and 2.1 m from the tree trunk observed in the trickle treatments as compared to the flood check resulted from the more favorable soil environment for root growth in the former: because of frequent irrigation the soil water matric potential was always high, whereas for the flood check the head fluctuated between irrigation. The effect of irrigation method also had a large effect on the root distribution with depth (Figs. 24, 25 and A-4) for the same reason. The root lengths for the flood irrigated treatment (Fig. 25) were relatively constant with depth. For the trickle irrigated trees, however, root length within the wetted area decreased rapidly with depth, while 2.7 m from the trunk it stayed constant (Figs. 24, A-4).

Root length distribution with soil depth was similar to water uptake distribution. Based on soil chloride concentrations, about 90% of the water uptake occurred above a soil depth of 0.6 m (Table 7). The soil water content profile reported by Dirksen et al. (1979) indicates that 74% of the water is taken up above 0.6 m. Using the root distribution data of Fig. A-4, an estimate of 75% results.

TABLE 14. AVERAGE ROOT LENGTHS WITHIN THE ROOT ZONE FOR EACH LEACHING TREATMENT AND FLOOD CHECK AS A FUNCTION OF DISTANCE FROM THE TREE TRUNK

Treatment	Distance from Tree Trunk, m			Treatment Average
	1.5	2.1	2.7	
	km m^{-3}			
5% leaching	20*	15	7	14**
10% leaching	21	20	9	17
20% leaching	21	17	10	16
Flood check	8	8	6	7

* The least significant difference at the 5% confidence level ($LSD_{.05}$) is 1.5. Number of root samples (n) for each value is 25.

** $LSD_{.05}$ = 0.8; n = 75.

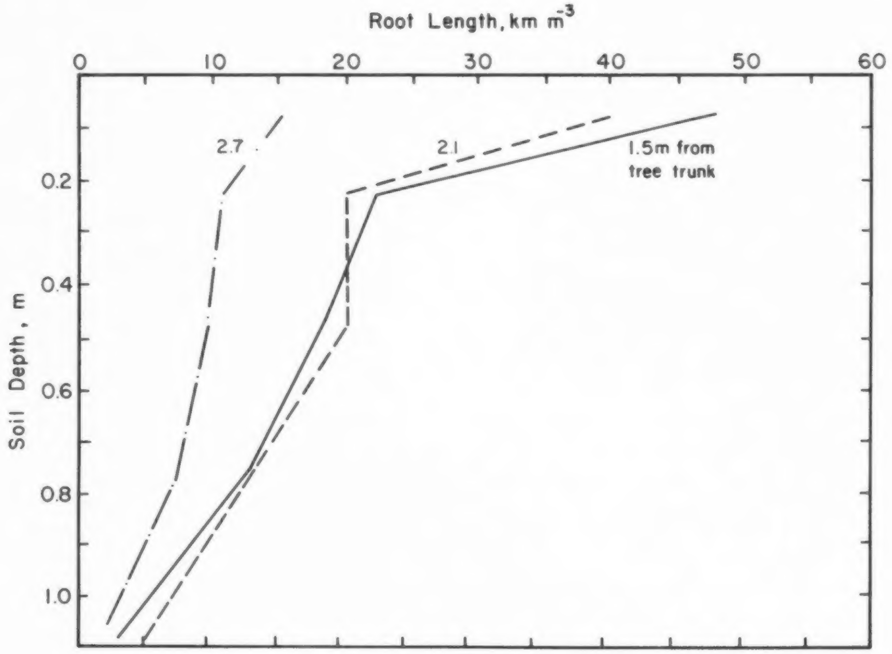

Fig. 24. Root length for the 10% leaching treatment and the flood check as a function of distance away from the trunk and soil depth.

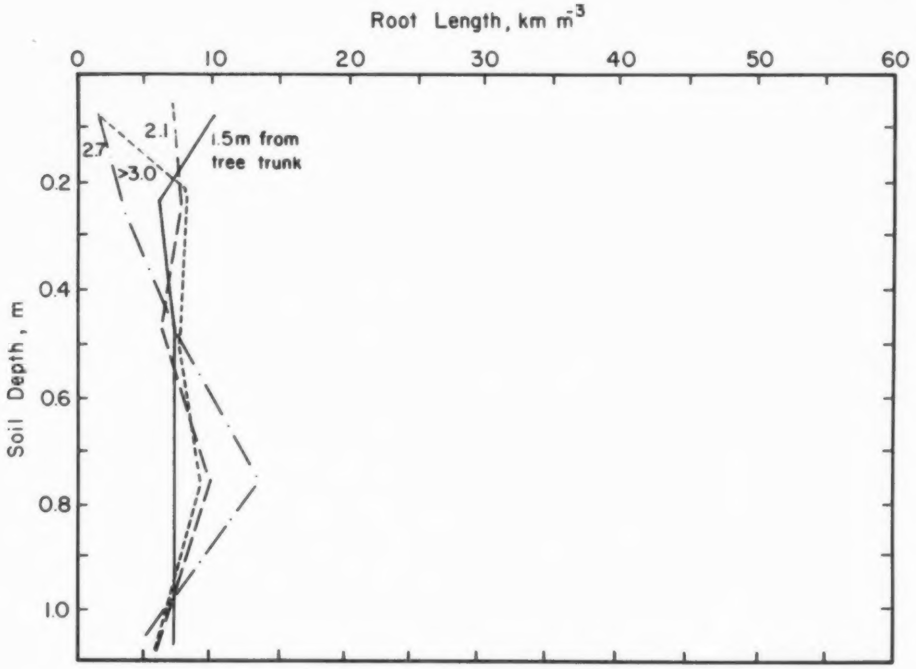

Fig. 25. Root lengths of the flood check as a function of distance away from the trunk and soil depth.

Similar correspondence between root length and water uptake can be shown to have occurred within the 0- to 1.2-m depth interval as a function of distance from the trunk for the 20% leaching treatment (Table 15). Using again the data for replicate H4 as reported by Dirksen et al. (1979), relative water uptake rates at different distances from the trunk, referenced to those 1.5 m from the tree, are about equal to the corresponding relative root lengths. This suggests that the water uptake per unit length of root was nearly constant at different distances from the tree. Apparently, the decreasing soil water matric potential and osmotic potential which occurred with increasing distance from the tree did not affect water uptake per unit length of root very much.

Yield and Fruit Quality

The average yields per tree for the three leaching treatments are presented in Table 16, along with the average yield for the border and check plot trees. The average yield per tree for each replication of the experiment and for each row of the border and check plot trees is given in Table A-6. Analysis of variance showed no significant differences in yield among leaching treatments until the last year (1979 harvest). Bingham et al. (1974) also reported that differences did not occur in an irrigation water quality trial on orange trees until the fourth year of their study. Yields from the borders and check plots were not significantly different from the experimental trees although they were more variable. Yields were consistently larger from the fertilized check plot and for some years from the drip irrigated border. Historically, the east side of the grove, where the fertilizer check plot and drip irrigated border are located, has a higher

TABLE 15. SPATIAL DISTRIBUTION OF WATER UPTAKE AND ROOT LENGTH IN THE 0-TO 1.2-m DEPTH INTERVAL FOR THE 20% LEACHING TREATMENT

Distance from Trunk	Daily Water Uptake Rate*		Root Length	Relative Water Uptake		Relative Root Length
	6/15-6/22	6/15-7/11		6/15-6/22	6/15-7/11	
m	---- mm ----		km m^{-3}			
1.5	7.0	4.0	14.1	1.0	1.0	1.0
2.1	6.0	3.4	12.0	0.9	0.8	0.8
2.7	3.0	2.6	7.2	0.4	0.6	0.5
3.6	4.0	2.6	5.7	0.6	0.6	0.4

* From Fig. 7 of Dirksen et al. (1979).

yield than the west side. The average yields from the flood irrigated plots indicated that leaching in excess of 20% does not increase yield.

The 25% reduction in yield during 1979 for 5% compared to the 20% leaching treatment indicates that the leaching fraction required to maintain full production, the leaching requirement (L_r), is in excess of 0.05 when Colorado River water is applied. The low yield at 10% compared to 20% leaching in 1979 (significantly different at the 10% confidence level) indicates a L_r between 10 and 20% Based on the model of Hoffman and van Genuchten (1981), the L_r would be 14%.

TABLE 16. AVERAGE ANNUAL VALENCIA ORANGE YIELD PER TREE (kg) FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Year	Leaching Treatment			LSD[1]	Border Trees		Check Plots		Weighted Average
	5%	10%	20%		Bubbler	Drip	Flood	Fertilizer	
1974	116	126	122	12	123	113	---[2]	---	120
1975	143	147	147	15	141	165	121	179	149
1976	74	70	71	15	77	88	98	105	83
1977	167	177	173	10	174	169	131	174	166
1978	143	138	142	17	139	159	126	197	149
1979	86**	106*	118	15	100	68	139	134	110
6-yr Mean	122	128	129		126	127	123	158	130

[1] LSD, least significant difference; values are significantly different from the 20% leaching treatment at the *10% confidence level and ** 5% confidence level.

[2] Trees were not harvested individually in 1974.

The average number of fruit harvested per tree is summarized in Table 17. The average number of fruit harvested per tree for each replication of the experiment and for each row of the border and check plot trees are given in Table A-7. The number of fruit harvested agrees well with the weight of fruit harvested. As for yield, the number of fruit was significantly lower for 5% leaching (5% level) and for 10% leaching (10% level) than for 20% leaching in 1979. Average fruit size as a function of the leaching treatments and the borders and check plots is summarized in Table 18. Although fruit size (measured by ring size and fruit mass, length, and width) changed in direct proportion to changes in yield from year to year, fruit size was not influenced significantly by the leaching treatment, even in 1979. The yield reduction in 1979 was, therefore, caused primarily by a reduction in the number of fruit harvested. Yield reductions caused by a reduction in fruit number with increasing soil salinity have been reported for both Valencia orange (Francois and Clark, 1980) and grapefruit (Bielorai, Shalhevet, and Levy, 1978).

TABLE 17. AVERAGE NUMBER OF VALENCIA ORANGE FRUIT HARVESTED PER TREE EACH YEAR FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Year	Leaching Treatment			LSD[1]	Border Trees		Check Plots		Weighted Average
	5%	10%	20%		Bubbler	Drip	Flood	Fertilizer	
1974	520	558	559	77	550	478	--- [2] ---		536
1975	787	799	781	80	706	872	518	939	770
1976	330	300	309	70	316	350	426	407	350
1977	863	910	884	63	842	851	706	899	851
1978	746	684	666	90	697	847	564	959	734
1979	534**	632*	718	88	634	446	841	725	658
6-yr Mean	630	647	653		624	641	611	786	650

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[1] LSD, least significant difference from the 20% leaching treatment values are significantly different different at the *10% confidence level and **5% confidence level.

[2] Trees were not harvested individually in 1974.

TABLE 18. AVERAGE SIZE OF VALENCIA ORANGE FRUIT FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Measure of Fruit Size	Year	Leaching Treatment 5%	10%	20%	Border Trees Bubbler	Drip	Check Plots Flood	Fertilizer	Weighted* Average
Ring Size†	1974	70	68	69	72	64	75	---	71
	1975	82	81	79	75	86	68	81	79
	1976	70	68	71	65	63	70	66	68
	1977	80	78	81	79	79	80	80	80
	1978	77	74	72	77	77	70	73	74
	1979	92	89	93	90	89	87	77	88
	Mean	78	76	78	76	76	75	75	76
Fruit Mass, g.	1974	222	226	218	224	236	---	---	224
	1975	182	185	188	200	189	234	191	196
	1976	224	233	230	244	251	230	258	238
	1977	194	195	196	207	199	186	194	195
	1978	192	202	213	199	188	223	205	204
	1979	161	168	164	158	152	165	185	166
	Mean	196	202	202	205	202	208	207	204
Fruit Length, mm	1974	80	81	81	81	84	78	--	80
	1975	77	78	78	81	78	84	78	79
	1976	84	85	84	88	86	84	85	85
	1977	78	79	78	79	79	79	78	79
	1978	79	80	81	81	79	84	81	81
	1979	76	76	75	78	75	80	72	76
	Mean	79	80	80	81	80	82	79	80
Fruit Width, mm	1974	74	75	74	74	77	72	--	74
	1975	72	72	73	75	71	77	72	73
	1976	76	77	76	77	79	76	76	77
	1977	72	73	72	73	73	72	73	73
	1978	72	73	74	72	72	75	74	73
	1979	69	70	69	70	69	70	73	70
	Mean	72	73	73	74	74	74	73	73

---

[*] The weighted average is based on samples from 81 trees in each of the leaching treatments and check plots and 54 trees from each of the border tree plots.

[†] Ring size is equivalent to the average number of fruit to a standard size shipping cartons.

The average annual value of each measure of fruit quality is presented in Table 19. None of the fruit quality measurements differed significantly among the leaching treatments in any year. On the average, the rind texture for the flood checks and bubbler border were slightly rougher than for the leaching treatments.

Results of the annual juice analyses are given in Tables 20 and 21. The ratio of TDS to TA changes from year to year depending upon the weather and the harvest date. As orange fruit ripens, the TDS/TA ratio increases because TDS decreases slower than does TA. The legal minimum ratio for the sale of oranges is eight. Juice quality did not differ significantly among leaching treatments in any year. In general, fruit from the flood checks were not as ripe as from the other treatments, as is evident from a lower TDS/TA ratio. The fraction of the fruit that is juice, reported as percent juice in Table 21, is also lower for the flood check than for the leaching treatments -- a further indication that the fruit from the flood check were not as ripe as those from the leaching treatments.

Leaf Analysis.

The mineral composition of leaves sampled October 1976 and earlier was reported in previous annual reports. The composition of leaves sampled in 1977 and 1978 is shown in Tables 22 and 23. The data are reported as means for the three leaching treatments, two border, and two check plots.

The nutritional status of the trees was reasonably uniform among all plots throughout the study and within reasonable limits although P and Mn concentrations tended to decrease after 1976. Generally, treatment effects on leaf composition were insignificant; however, in 1978 P, Fe, and Mn concentrations increased significantly with decreased leaching.

On the basis of leaf analysis standards (Embleton et al. 1976), P and Mn were below optimum levels the last 2 years while N was slightly above optimum. Boron concentrations were consistently high every year but there was no evidence of any toxicity. The source of boron was never identified. Both the soil and irrigation water were low in boron. Likewise, no source of boron was found in the laboratory analysis procedure. Leaf Cl concentrations increased throughout the experiment and were significantly higher in the low leaching treatments; however, they remained within acceptable levels. The trend toward increasing Cl accumulation indicates that Cl could eventually become a problem with continued low leaching.

Trunk Circumference

The average annual increases in trunk circumference for the leaching treatments, the borders, and the check plots are given in Table 24. The annual measurements of circumference, averaged by replication for the leaching treatments and by row for the borders and check plots, are given in Table A-8.

TABLE 19. AVERAGE QUALITY OF VALENCIA ORANGE FRUIT FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Quality Measure	Year	Leaching Treatment			Border Trees		Check Plots		Weighted Average
		5%	10%	20%	Bubbler	Drip	Flood	Fertilizer	
Rind Color*	1974	10.3	10.3	10.3	10.2	10.1	10.4	---	10.3
	1975	10.4	10.4	10.4	10.4	10.3	10.4	10.4	10.4
	1976	10.4	10.4	10.4	10.5	10.3	10.4	10.3	10.4
	1977	10.0	10.0	10.0	10.4	10.2	10.1	9.9	10.1
	1978	9.9	10.0	9.9	10.0	10.0	10.1	10.0	10.0
	1979	10.1	9.9	10.0	10.2	10.2	10.3	10.2	10.1
	Mean	10.2	10.2	10.2	10.3	10.2	10.3	10.2	10.2
Rind Texture†	1974	3.3	3.3	3.3	3.2	3.5	3.3	--	3.3
	1975	3.2	3.3	3.3	3.4	2.9	3.8	3.3	3.3
	1976	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.2
	1977	4.1	4.2	4.1	4.2	4.1	4.1	4.2	4.1
	1978	3.8	3.9	3.8	4.3	3.7	4.1	3.9	3.9
	1979	3.5	3.5	3.4	4.0	3.6	3.9	3.7	3.6
	Mean	3.7	3.7	3.7	3.9	3.7	3.9	3.9	3.7

* Rind color is denoted by a numerical scale from 3 (dark green) to 13 (orange-red).

† Rind texture is evaluated on a numerical scale from 1 (smooth) to 6 (very rough).

TABLE 20. AVERAGE QUALITY OF VALENCIA ORANGE JUICE FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979 AT THE TIME OF HARVEST

Measure of Juice Quality	Year	Leaching Treatment			Border Trees		Check Plots		Weighted
		5%	10%	20%	Bubbler	Drip	Flood	Fertilizer	Average
Total Dissolved Solids, % *	1974	9.7	9.8	9.8	10.0	9.1	10.0	---	9.8
	1975	10.3	10.1	10.0	10.0	10.1	10.0	10.1	10.1
	1976	9.9	9.9	9.8	9.8	9.7	10.2	9.7	9.9
	1977	9.7	9.5	9.5	9.5	9.3	10.4	9.6	9.7
	1978	11.2	11.0	10.8	11.6	11.2	11.0	10.1	10.9
	1979	9.5	9.5	9.3	10.0	9.4	10.1	9.2	9.6
	Mean	10.1	10.0	9.9	10.2	9.8	10.3	9.7	10.0
Total Acid, % †	1974	0.90	0.89	0.90	0.89	0.83	0.93	--	0.89
	1975	1.03	1.01	1.00	0.97	1.00	1.04	1.02	1.01
	1976	0.99	0.99	0.98	0.94	0.93	1.10	0.97	0.99
	1977	1.05	1.05	1.05	1.04	0.98	1.19	1.06	1.07
	1978	0.95	0.91	0.89	1.04	0.90	0.92	0.81	0.91
	1979	0.83	0.83	0.82	0.87	0.85	0.94	0.85	0.86
	Mean	0.96	0.95	0.94	0.96	0.92	1.02	0.94	0.96
Ratio, TDS/TA	1974	10.8	11.0	10.9	11.2	11.0	10.7	---	11.0
	1975	10.0	10.0	10.0	10.3	10.1	9.6	9.9	10.0
	1976	10.0	10.0	10.0	10.5	10.3	9.2	10.0	10.0
	1977	9.2	9.1	9.1	9.2	9.5	8.8	9.1	9.1
	1978	11.9	12.2	12.2	11.3	12.4	12.0	12.4	12.1
	1979	11.4	11.5	11.3	11.6	11.1	10.8	10.9	11.2
	Mean	10.6	10.6	10.6	10.7	10.7	10.2	10.5	10.6

---

* Total dissolved solids are determined with a Brix hydrometer or refractometer. Total dissolved solids in orange juice consist mainly of sucrose, fructose, and citric acid, together with potassium, calcium, magnesium, and sodium salts.

† Total acid refers to the titratable acidity and is determined volumetrically by the amount of standard alkali necessary to neutralize the acid in a known amount of juice. The acid in orange juice consists mainly of citric acid with small amounts of malic, tartaric, and succinic acids.

TABLE 21. AVERAGE QUANTITY OF JUICE IN THE VALENCIA ORANGES HARVESTED FROM THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Measure of Juice Quantity	Year	Leaching Treatment			Border Trees		Check Plots		Weighted Average
		5%	10%	20%	Bubbler	Drip	Flood	Fertilizer	
Percent Juice*	1974	44.3	44.1	44.6	44.3	42.5	41.8	---	43.6
	1975	43.7	43.2	42.7	43.1	43.9	39.3	43.3	42.9
	1976	41.4	40.9	40.6	38.4	41.8	36.6	41.6	40.2
	1977	45.5	44.6	44.3	42.9	46.1	42.9	44.3	44.4
	1978	47.6	46.9	47.1	47.1	48.4	40.8	48.1	46.8
	1979	37.8	39.1	38.2	31.4	40.6	35.1	43.0	38.3
	Mean	43.4	43.1	42.9	41.2	43.9	39.4	44.1	42.7
Extractable Total Dissolved Solids, % †	1974	3.6	3.7	3.7	3.8	3.3	3.6	---	3.6
	1975	3.8	3.7	3.6	3.7	3.8	3.3	3.7	3.7
	1976	3.4	3.4	3.4	3.1	3.4	3.2	3.4	3.4
	1977	3.7	3.6	3.6	3.4	3.7	3.8	3.6	3.6
	1978	4.5	4.4	4.3	4.6	4.6	3.8	4.1	4.3
	1979	3.0	3.1	3.0	2.7	3.2	3.0	3.4	3.1
	Mean	3.7	3.7	3.6	3.6	3.7	3.5	3.6	3.6

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* The percent of the total fruit mass that is juice is the percent juice.

† The juice plant can extract only about 85% as much juice as can the laboratory. Thus, the grower is paid on the basis of 85% of the total dissolved solids per fruit.

TABLE 22. MINERAL COMPOSITION OF VALENCIA ORANGE LEAVES SAMPLED OCTOBER 1977

Element	Unit	Optimum Range*	Leaching Treatments			Border Trees		Check Plots	
			5%	10%	20%	Bubbler	Drip	Flood	Fertilizer
N	g/kg	24-26	28	28	27	27	29	23	28
P	mmol/kg	38-52	37	34	32	34	52	35	39
K	"	180-280	290	280	300	300	440	380	330
Ca	"	750-1375	1075	1080	1075	1085	780	1070	1030
Mg	"	105-250	105	105	100	100	105	100	95
Na	"	<70	15	15	14	15	8	10	12
Cl	"	<80	47	36	25	15	36	8	8
S	"	60-95	100	95	95	95	85	110	90
B	mg/kg	31-100	173	183	172	147	200	187	187
Fe	"	60-120	75	72	67	77	48	79	65
Mn	"	25-200	24	20	23	23	22	19	19
Zn	"	25-100	26	26	26	24	20	18	26
Cu	"	5-16	9	9	9	9	8	10	9

* Optimum range based on standards by Embleton et al., 1976.

TABLE 23. MINERAL COMPOSITION OF VALENCIA ORANGE LEAVES SAMPLED SEPTEMBER 1978

Element	Unit	Optimum Range*	Leaching Treatments			Border Trees		Check Plots	
			5%	10%	20%	Bubbler	Drip	Flood	Fertilizer
N	g/kg	24-26	28	30	29	32	32	25	33
P	mmol/kg	38-52	32	30	28	31	32	32	34
K	"	180-280	300	300	300	320	290	380	300
Ca	"	750-1375	995	990	1015	1010	900	1035	965
Mg	"	105-250	105	105	100	105	85	95	90
Na	"	< 70	17	17	17	16	20	7	16
Cl	"	< 80	71	56	35	37	48	9	10
S	"	60-95	100	100	100	80	90	110	90
B	mg/kg	31-100	207	210	206	162	187	197	209
Fe	"	60-120	64	53	48	69	61	42	51
Mn	"	25-200	27	22	18	30	30	22	22
Zn	"	25-100	29	29	29	31	33	18	27
Cu	"	5-16	9	9	9	9	7	9	7

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* Optimum range based on standards by Embleton et al., 1976

TABLE 24. AVERAGE ANNUAL INCREASE IN TRUNK CIRCUMFERENCE (mm/TREE) OF VALENCIA ORANGE TREES FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1973 TO 1979

Growth	Leaching Treatment			Border Trees		Check Plots	
Period	5%	10%	20%	Bubbler	Drip	Flood	Fertilizer
1973-74	5	15	15	25	20	--	--
1974-75	35	35	35	40	15	--	--
1975-76	35	35	40	25	50	25	25
1976-77	30	20	30	35	30	20	30
1977-78	30	30	30	20	25	20	20
Total Growth Sept 1973 to July 1978	135	135	150	145	140	--	--

There have been no significant differences in trunk circumferences among leaching treatments. Analysis of variance showed, however, that the mean trunk circumferences for all three leaching treatments have enlarged significantly each year with the exception of the 5% leaching treatment during the initial year. The mean trunk circumference of the experimental trees increased from 4 to 6% annually except the first year when it increased only 2%. Although less consistent than the experimental trees, the border trees have made similar growth. Measurements were not taken every year on the check plot trees, so comparisons during the initial two years are not possible. However, they seem to be growing as rapidly as the experimental trees, although they are smaller and more variable in size.

Soil Air

The soil oxygen results are summarized in Table 25. Soil oxygen concentrations above 10% are considered adequate for most crops. No measurements were below 10% in the citrus experiment, not even in the flood check 1 day after an irrigation. Thus, poor soil aeration is not expected to be a problem with trickle irrigation of citrus on these coarse-textured soils.

TABLE 25. COMPARISON OF THE PERCENT SOIL OXYGEN AT THE 0.45-m SOIL DEPTH AND 1.5 m OUT FROM THE VALENCIA ORANGE TREE TRUNK FOR SEVERAL IRRIGATION TREATMENTS

Date	Leaching Treatments		Border Trees		Flood Check
	5%	20%	Bubbler	Drip	
Feb. 1975	17.4	20.1	19.8	20.4	20.2
June & July 1975	18.1	14.8	18.2	18.5	20.2

The carbon dioxide concentrations in the soil air (Table 26) were affected by time of year, but not by soil depth. They were higher during the summer months (May-October) than in January because of increased root and microbial respiration and increased soil-water content. The former results in greater rates of carbon dioxide production and the latter increases the resistance to carbon dioxide exchange with the atmosphere.

TABLE 26. AVERAGE PERCENT CARBON DIOXIDE IN SOIL AIR UNDER MATURE CITRUS TREES AS A FUNCTION OF TIME AND SOIL DEPTH

Soil Depth m	Oct 1975	Jan 1976	Mar 1976	May 1976
0.3	2.8	0.4	1.7	2.5
0.6	3.0	0.4	1.5	3.2
0.9	3.0	0.6	1.7	2.4
1.2	3.0	0.6	1.5	2.6

Incidence of Phytophtera

The incidence of Phytophtera was checked visually during the first week of April 1979. Only the trees that had been treated by peeling away the bark of the trunk and applying copper sulfate were counted as being affected by Phytophtera. Thus, the criterion used was the judgment of the farm manager that treatment had been warranted.

In the trees irrigated by border flood in the 4-ha block of trees west of this experiment, over 30% of the trees were treated and on the west edge of the block in an area of over 600 trees over 60% were treated. In a comparison drip irrigation experiment of the University of Arizona located about 500 meters to the west, about 6% of the trees had Phytophtera.

These observation, although far from conclusive, strongly suggest that drip irrigation has the potential of preventing the spread of Phytophtera in Valencia orange.

DISCUSSION

The objective of the citrus experiment was to demonstrate that, in situations such as found in southwest Arizona, the amount of salt in the irrigation return flow (drainage water) could be reduced substantially by reducing the amount of irrigation water used, without adverse effect on crop yield; and to determine just how much of a reduction was feasible. To make this evaluation, the values of several parameters, notably, evapotranspiration, leaching fractions achieved, and the leaching requirement, are needed. This discussion reviews the estimates of evapotranspiration and leaching fraction and arrives at consensus values, places limits on the leaching requirement, and finally estimates the possible reduction in the salt load of irrigation return flow with efficient irrigation systems.

Evapotranspiration and Leaching Fraction

A number of estimates have been presented of the evapotranspiration and leaching fractions obtained in the experiment. One estimate of L was obtained from the Cl concentration at the bottom of the root zone by selecting periods of record that appeared close to steady state (Table 7), and assuming one-dimensional downward flow. Taking rainfall in account, the chloride concentration of the applied water is 3.4 mol m^{-3} rather than 3.7 mol m^{-3} in the irrigation water. The resultant leaching fractions (Cl_i/Cl_d) were L_L = 0.12 and L_H = 0.27, where the subscripts refer to the leaching treatment imposed. Recognizing that there was three-dimensional flow (Fig. 13), upper and lower limits were estimated from Cl data (p.37) as follows: $0.05 < L_L < 0.11$ and $0.11 < L_H < 0.31$ after correcting for rainfall. A third estimate, obtained from the electrical conductivity of the soil solution (p. 43), yielded $0.05 < L_M < 0.16$ and $0.08 < L_H < 0.25$. All three of these estimates were obtained by considering a selected set of data, where the selection was based on an evaluation that a quasi-steady state seemed to have been reached. A fourth estimate, not dependent on such an assumption, is based on the Cl concentration of the leachate caught in the vacuum extractors (Table 13). Taking the average for years 1975-78, one obtains the estimate L_H = 0.22, L_M = 0.15 and L_L = 0.11. These various estimates of leaching fraction are summarized in Table 27.

An entirely different approach depends on the water balance. A direct measure would result from comparing water applied with drainage water as caught in the vacuum extractors. Unfortunately, drainage volumes captured by the vacuum extractors clearly were far too unreliable; thus, extracted volumes were not used to estimate L.

Three other approaches were used. First, the amount of water applied was partitioned into evapotranspiration and deep percolation by assuming that the leaching fraction obtained was that planned. It yielded an estimate of 1470 mm for annual ET (Table 11). Secondly, the ET was estimated independently by five different predictive equations (Table 11). Thirdly, an attempt was made to establish a relation between pan evaporation and ET, and this relation was used to estimate annual ET. It again yielded 1470 mm

TABLE 27. COMPARISON OF ESTIMATES OF LEACHING FRACTIONS ACHIEVED BASED ON SOIL WATER CHLORIDE AND SOIL SALINITY DATA*

	L_L	L_M	L_H
	--	--	--
One-dimensional, † Cl sampling	0.12	--	0.27
Three-dimensionsal, ≠ Cl sampling	0.05	--	0.11
One-dimensional, † soil salinity	--	0.16	0.25
Three-dimensional, ≠ soil salinity	--	0.05	0.08
Extractor Cl	0.11	0.14	0.22

* L-values differ slightly from preceding text, because Cl_i was here corrected for rainwater to 3.4 mol m^{-3}.

† - Upper limits

≠ - Lower limits

(p. 54). Summarizing the results for these three approaches (Table 28), one may conclude by inspection that the estimates of 1470 mm for ET and 0.05, 0.10 and 0.21 for L are reasonable. One also can determine a mean--a quite arbitrary procedure-and arrive at a very similar conclusion.

Although the chemical data suggest a wider range of estimates, it appears that they are consistent with the above conclusions. Thus we propose that the ET for Valencia oranges in Wellton-Mohawk is close to 1470 mm and that the leaching fractions obtained in the experiment were very close to the intended values of 0.05, 0.10 and 0.20.

Leaching Requirement and Crop Yields

Except for the last year of the 5-year experiment, no effect of irrigation treatment was observed on fruit yield or quality. Citrus yields (Table 16) fluctuated widely from year to year, a normal pattern for Valencia orange, and the last year was a low yield year. Nevertheless, yields in the 5% leaching treatment were depressed in yield substantially more than the others. Thus one must conclude that the last year's yield reduction was probably a real effect of salinity and, had the experiment continued longer, one could reasonably expect further yield effects. Unfortunately, part of

TABLE 28. COMPARISON OF ESTIMATES OF EVAPOTRANSPIRATION AND LEACHING FRACTIONS ACHIEVED IN THE CITRUS EXPERIMENT BASED ON WATER BALANCE DATA (MEASURED) AND PREDICTIVE EQUATIONS FOR EVAPOTRANSPIRATION

	"Measured"	Pan Evaporation	Radiation	Jensen-Haise	Blaney Criddle	Modified Penman	Mean
Evapotranspiration (mm)	1470	1450	1360	1420	1520	1660	1480
		5% Leaching Treatment					
Irrigation Depth (mm)	1550						
Drainage Depth (mm)	80	100	190	130	30	-110	70
Leaching Fraction	0.05	0.06	0.12	0.08	0.02	-0.07	0.05
		10% Leaching Treatment					
Irrigation Depth (mm)	1630						
Drainage Depth (mm)	160	180	270	210	110	-30	150
Leaching Fracton	0.10	0.11	0.17	0.13	0.07	-0.02	0.09
		20% Leaching Treatment					
Irrigation Depth (mm)	1860						
Drainage Depth (mm)	390	410	500	440	340	200	380
Leaching Fraction	0.21	0.22	0.27	0.24	0.18	0.11	0.20

this is speculation. It is supported, however, by similar observations of others (Bingham et al., 1974).

It is more difficult to draw clear conclusions about the leaching requirement than the leaching fraction. With the irrigation water used, L_r clearly exceeds 0.05 but is less than 0.20. A more definitive statement probably would suggest more information than is contained in the data.

A related issue of some interest concerns the nutritional status of the trees. Chloride levels in the leaves increased with time but never recorded a "high" level; it is possible that the capacity to store chloride in the woody tissue was sufficient to prevent reaching equilibrium in the time of study, thus leaving open the possibility of greater yield reductions in the future. The trees were fertilized with 690 g of nitrogen per tree each year. There were no indications of nitrogen shortage; if anything, foliar N levels were on the high side (Tables 22 and 23). University of Arizona experience in an adjacent test area indicated that 340 g/tree of N was probably borderline for optimum production, thus verifying that fertilization with 690 g/tree of N is wasteful.

Salinity Status of Soil

The short-term fluctuations, the spatial heterogenity and the multidimensional nature of the root- and flow-systems make it difficult to interpret the data. Nevertheless, certain conclusions can be drawn unequivocally. The time elapsed between beginning and end of the experiment was insufficient to obtain chemical equilibrium with respect to Na, Ca or Mg, and thus R_{Na} (Fig 9). With reference to chloride, it is more likely that (quasi-) equilibrium was indeed reached as was also the case for electrical conductivity (soil salinity).

Salt Load Reduction

In the Interim Report (USSL Staff, 1977), a calculation was presented to illustrate the potential of reducing the salt load in the return flow by 45,000 Mg yr^{-1} by increasing irrigation efficiency to 80% on 3000 ha of citrus, or the quantity of salt exported in the short run (presumably to the desalting plant) by 130,000 Mg yr^{-1}.

Conceptually, these estimates are still valid although reduction in citrus area by government purchase of land has changed the situation significantly. Yet the objective of the study reported here, to demonstrate a substantial opportunity for reducing the salt load of the return flow, was met.

For readers who do not have access to the earlier report, we briefly repeat the argument here, with slightly different data.

Given a historic annual water application of 3.2 m, a proposed annual application providing 20% leaching with ET = 1470 mm, and an irrigation water salt load of 944 g m^{-3}, the annual change in water delivered (diverted) per ha is

$$\Delta V = [3.2- 1.47/(1-0.20)] \times 10^4 \text{ m}^3 = 1.36 \times 10^4 \text{ m}^3 \quad (10)$$

and the annual change in salt load of the water leaving the root zone, at equilibrium, is

$$\Delta S = 0.944\ \Delta V \text{ kg ha}^{-1} = 12.8 \text{ Mg ha}^{-1}. \quad (11)$$

This estimate may be corrected for lime precipitation by increasing it 11%, so that finally

$$\Delta S = 14.2 \text{ Mg ha}^{-1}. \quad (12)$$

In the short run, the reduction in salt in the return flow would be much larger because the drainage water averages far more than 944 g m^{-3}.

SECTION 4

ALFALFA

EXPERIMENTAL PROCEDURE

Experimental Design

The alfalfa experiment was located 13 km northeast of Tacna, Arizona, on the Snyder Ranch in the flood plain of the Gila River. The experimental site was the northern quarter of an 8-ha field that had been previously cropped to alfalfa and flood irrigated. Within 400 m of the south end of the field, the topography rises more than 15 m to a mesa where citrus is grown. There was a drainage well for water table control adjacent to the southwest corner of the field. The experimental site was instrumented and the irrigation system installed during September 1974. After cultivation, alfalfa (*Medicago sativa* L., cv. Hayden) was planted in early October. All crop management practices, such as cultivating, planting, harvesting, and pest and weed control, were performed by Snyder Ranch personnel.

The experimental design, shown in Fig. 26, consisted of 5, 10, and 20% leaching treatments, each replicated five times. Each plot was 12.2 m wide and 104 m long. The remainder of the 8-ha field was irrigated by the rancher using level-basin flooding. This section of the field is referred to as the flood check.

Soil Properties

Soil Conservation Service personnel examined several soil profiles within the experimental site and classifed the soil as Indio fine sandy loam (Typic Torrifluvent, coarse-silty, mixed, hyperthermic). The soil description prepared by the SCS for one of the soil profiles is given in Table B-1 of the Appendix. The soil is calcareous, moderately sodic, well drained, and representative of the valley soils in the district. The soil profile texture grades from very fine sandy loam to silt loam at a depth of 0.3 m, and to silty clay loam at a depth of 0.8 m.

Following the first harvest in February 1975, 303 soil samples were collected to characterize initial soil conditions and determine the initial soil salinity distribution. Six locations were sampled in each of the six instrumented plots (those adjacent to the manholes, Fig. 26). These 36 locations were sampled by 0.3-m increments, 21 to a depth of 1.5 m and 15 to

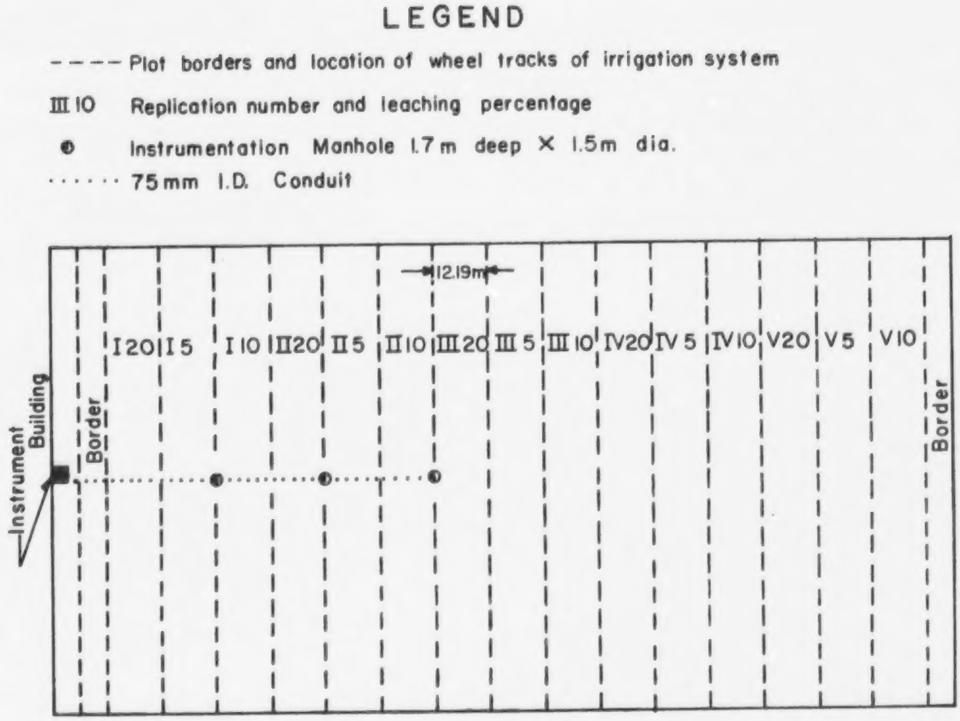

LEGEND
---- Plot borders and location of wheel tracks of irrigation system
III 10 Replication number and leaching percentage
● Instrumentation Manhole 1.7 m deep × 1.5 m dia.
······ 75 mm I.D. Conduit
12.19m
I 20
I 5
I 10
II 20
II 5
II 10
III 20
III 5
III 10
IV 20
IV 5
IV 10
V 20
V 5
V 10
Instrument Building
Border
Border

Fig. 26. Design of minimum leaching experiment for alfalfa in southwestern Arizona.

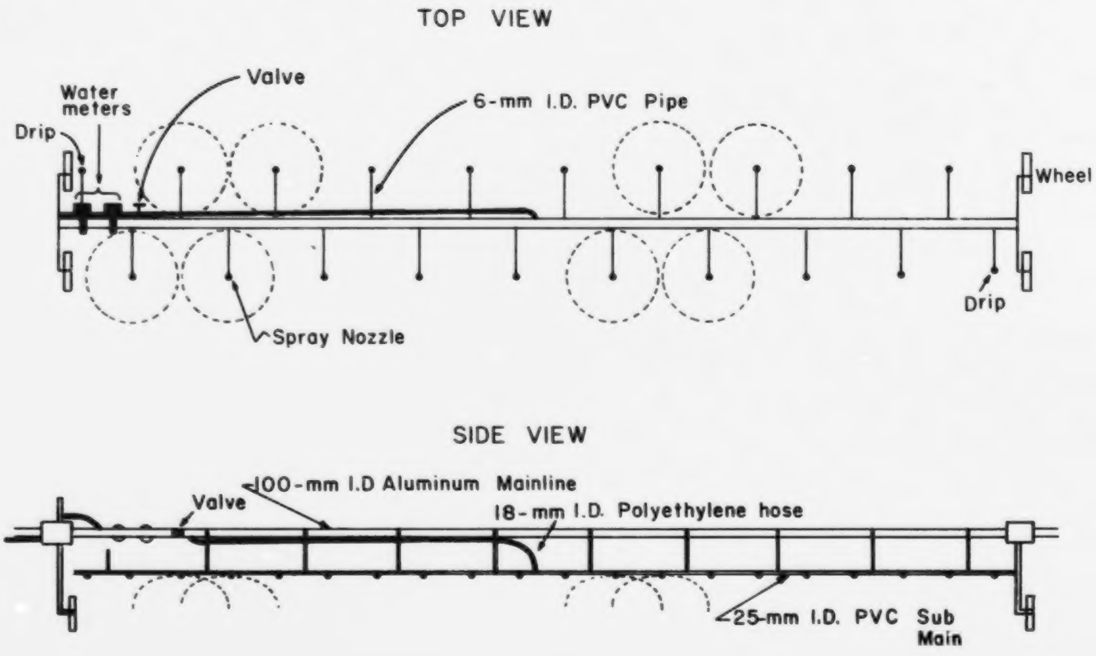
a depth of 2.4 m. Twelve locations were sampled in the flood check, six to a depth of 1.5 m and six to 2.4. All of the samples were subjected to the same analyses as those collected in the citrus experiment. As in the citrus, the relationship between hydraulic conductivity and matric potential was determined in the laboratory on three undisturbed soil columns, each 0.9 m deep, taken in the fall of 1974.

Irrigation

The irrigation water, pump, and filter system were identical to those used for the citrus. Water was applied with an electrically driven, lateral-move irrigation system 195 m long, with wheel towers spaced 12.2 m apart (see Figs. 27 and 28). The irrigation system was operated with impact sprinklers spaced at 12.2-m intervals along the main line for the first month after planting. On Nov. 8, 1974, after the crop was well established, the spray system shown in Fig. 27 was installed and differential irrigation treatments were initiated. During the first month of operation, several adjustments in alignment of the system were required to keep it running in the same tracks. Problems also arose from water running into the wheel tracks, causing the system to mire. By filling the tracks with sand and by shielding spray nozzles near the wheels, these problems were overcome. The irrigation system shown in operation in Fig. 28, operated satisfactorily with little maintenance from early 1975 on.

Differential irrigation treatments were achieved by regulating the pressure in each section of submain with a throttle valve. By periodically adjusting the pressure, based on water meter readings, the average differences in accumulated water application between the three treatments were kept within 0.2% of those desired. Uniformity of water distribution within plots also was good. The standard deviation of water delivery rate from individual spray nozzles was about 0.02 ml s^{-1}, and the standard error of water delivery for a 2.4-m-wide section of a plot (irrigated with four spray nozzles) originally was within 0.01. By selectively interchanging up to one-sixth of the nozzles, the differences in water delivery rate among 2.4-m-wide sections of any plot were reduced to less than 0.1%. This was well within the required uniformity and was possibly the most uniform field irrigation system in existence at the time.

Until May 1977, the water for each plot was measured by two water meters in series and distributed through 20 nozzles (Fig. 27), which, at a pressure of 70 kPa, delivered 30 ml s^{-1} each. At a ground speed of 8 mm s^{-1}, the irrigation system applied 6 mm each pass. Thus, the number of passes varied from one every few days in winter to a maximum of two per day in summer. As stated in the Interim Report (U. S. Salinity Laboratory Staff, 1977), frequent irrigations with small quantities of water caused the soil water content to be higher near the soil surface than with infrequent irrigations. When the alfalfa was cut, this provided an ideal environment for germination and growth of grass and low-growing weeds; particularly in areas subject to harvest traffic. After May 1977, irrigation frequency was decreased to reduce the average soil water content near the surface and to increase the time interval before cutting when no water was applied to discourage weed


TOP VIEW

SIDE VIEW

Valve
Water meters
Drip
6-mm I.D. PVC Pipe
Wheel
Drip
Spray Nozzle
100-mm I.D Aluminum Mainline
Valve
18-mm I.D. Polyethylene hose
25-mm I.D. PVC Sub Main

Fig. 27. Spray system for one section of the lateral-move irrigation system serving one replication of the alfalfa experiment.

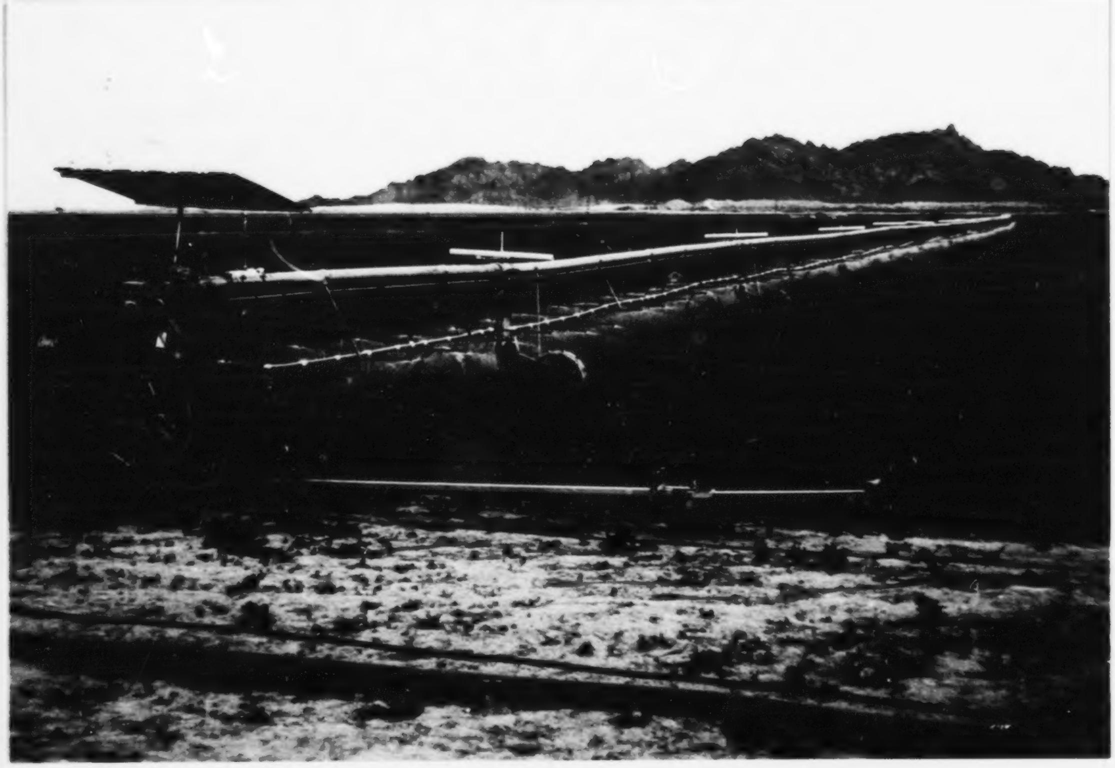


Fig. 28. Overall view of lateral-move irrigation system on the alfalfa experiment.

germination and growth. To decrease the irrigation frequency, the nozzle size was increased to deliver a greater flow rate and the travel speed of the irrigation system was decreased. Water delivery was measured with two water meters as before except between May and December of 1977 when only one meter of larger capacity was available for each plot. As a consequence each irrigation applied 70 mm of water as compared to 6 mm as originally designed. Because the pump capacity was limited, half of the plots were irrigated during a single pass.

Instrumentation

Two replications of each leaching treatment were instrumented from three concrete manholes, each installed at the border between two plots as shown in Fig. 29. The manholes facilitated automatic data collection and minimized interference with farming operations. A service building at the edge of the experimental plots contained a data processing and acquisition system. A conduit from this service building to the manholes, shown in Figs. 26 and 29, contained electric cables for automatic data collection, pressure and vacuum pipes, and service wires. Two 1.5-m-long vacuum extractors, similar in design to those for the citrus, were installed at the 1.2-m depth in each of the six instrumented plots.

Salinity sensors and tensiometers were installed as shown in Fig. 29. All of the tensiometers installed in September 1974 had to be replaced because the epoxy cement failed to seal the ceramic tensiometer cups to an acrylic adapter. New tensiometers were installed in February 1975. All sensor wires and tensiometer tubes leading to the manholes were buried at least 30 cm below the soil surface.

Initially, the 36 tensiometers near each manhole (including 16 over the vacuum extractors) were connected to two switching boxes housing 24-position hydraulic scanning valves, each controlled by an electric stepping switch. The pressure within each tensiometer, as well as that of a standard and zero reference, was measured with a pressure transducer producing a voltage signal. These voltages were converted to soil water hydraulic head readings by the data acquisition system. A calculator program was written to read the tensiometers at any desired time interval. All tensiometers and associated tubing could be flushed and recharged automatically whenever it was necessary to eliminate air bubbles. The first automatic tensiometer data were obtained in March 1975. Measurements were continued through September, but were often interrupted or inaccurate because of problems with the scanning valves. After September, these valves became completely unsatisfactory and the entire automatic scanning system had to be discarded. In March 1976, all tensiometers were connected to mercury manometers located within the manholes and read and recorded manually. The coaxial tubing for each tensiometer and a common shutoff device allowed all tensiometers in one manhole to be flushed simultaneously (Huber and Dirksen, 1978).

Starting on January 1975, the salinity sensors were read with the data acquisition system. Through a computer program, the unit activated stepping switches, read all 96 sensors in sequence, compensated the readings for soil

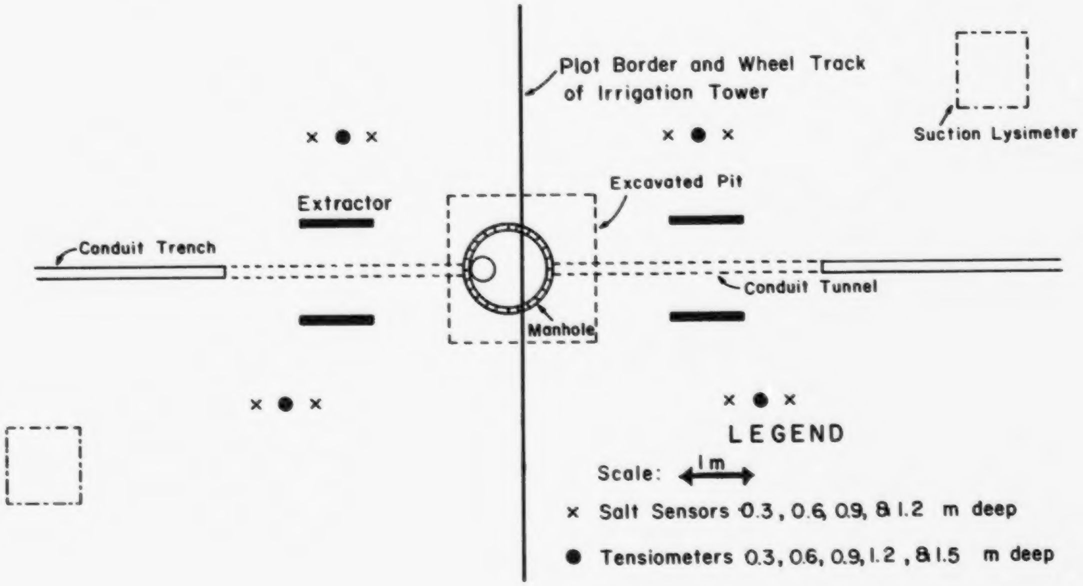

Plot Border and Wheel Track of Irrigation Tower
Suction Lysimeter
Excavated Pit
Extractor
Conduit Trench
Conduit Tunnel
Manhole
LEGEND
Scale: 1m
× Salt Sensors 0.3, 0.6, 0.9, & 1.2 m deep
● Tensiometers 0.3, 0.6, 0.9, 1.2, & 1.5 m deep

Fig. 29. Location of instruments for two of the six plots instrumented in the alfalfa experiment.

temperature, and printed out the calculated soil water electrical conductivities on paper tape. Readings taken automatically were nearly identical to those read manually. It required 20 minutes to read the sensors and produce the punched paper tape, which was then transmitted via teletype to Riverside for processing and analysis.

In addition to the vacuum extractors, a 1.2-m-deep suction lysimeter was installed in each of the six instrumented plots. These were formed by lining a 1.5-m-square hole with 250-)m-thick plastic film. A wooden frame, 0.3 m below the soil surface, served as the top lip of the lysimeter. After backfilling with about 0.1 m of soil, ceramic tubes, identical to those used in the vacuum extractors, were installed in each lysimeter to extract the leachate. The lysimeters were then filled with disturbed soil and compacted by saturating with water.

Check Plot

The portion of the 8-ha field not within the experimental areas served as a check and was irrigated as a level basin from a single gate located in one corner of the field. During each irrigation, a depth of about 150 mm was applied at the rate of about 0.4 $m^3 s^{-1}$. The application rate was measured with a critical-flow flume identical to that used in the citrus experiment. Salinity sensors were installed at four depths (0.3, 0.6, 0.9, and 1.2 m) in six locations in the check plot.

Chloride Samples

Soil samples for the determination of chloride concentrations were taken in December 1976 and were to be taken in October 1978. Samples obtained in 1978 were to be used to determine the depth of the root zone and to make a preliminary assessment of the water uptake distribution with depth. A preliminary assessment of rooting depth and water uptake distribution were based upon the samples taken in 1976. Replicate II20 and the flood check were sampled at six locations each. The samples were divided into 0.2-m increments to a depth of 2.4 m for chloride and soil water content determinations. In 1978, three replicates of each leaching treatment and the east, center, and west thirds of the flood check were to be sampled at nine locations. Samples obtained at three sites within the north, center, and south thirds of each sprinkler replicate or subsection of the flood check were to be composited for analysis. Unfortunately these final soil samples were not taken because the experiment was flooded accidentally during the first week of October 1978.

Crop Yield

The alfalfa was harvested by cutting with a windrower-conditioner and then cubed following customary procedures. Harvest dates were chosen by the ranch when the alfalfa was at approximately 50% bloom. The yield of each cutting was determined by weighing three samples from each replicate. The samples were taken from 26.8-m^2 areas in the north, center, and south sections of each plot from the first swath (4.4 m wide) made down the center of each plot. Nine similar samples were taken from the flood check at three locations in each of three windrows made in the east, center, and west sections of the field. Each sample was weighed and yields of air-dry alfalfa were calculated after measuring the water contents of representative subsamples.

Shoot Analysis

Alfalfa shoots were sampled for plant nutrient status at five locations randomly selected along the length of each experimental plot and along three lengths within the flood check. Each sample consisted of approximately 200 g fresh weight of plant shoots, cut about 50 mm above the soil surface. Samples were taken on September 16, 1975, October 4, 1977, and September 20, 1978 (6th, 7th, and 8th cuttings, respectively). The samples were washed, oven-dried, and analyzed for 13 mineral elements.

RESULTS

Soil Properties

Table 29 summarizes the initial soil chemical properties for the alfalfa experiment. The initial soil chemical properties for each instrumented replication by soil depth increments is given in the Appendix (Tables B-2 to B-6). The ratio of the standard deviation to the mean for the ionic concentrations is about 0.7. The chemical data were skewed: the mean generally exceeded the mode. Skewness was reduced when the data were log transformed indicating they were log normally distributed. Consequently, these standard deviations should not be used to estimate confidence intervals about the mean.

Generally, the soil chemistry is consistent with expectations based on long term irrigation with Colorado River water at a leaching fraction of about 0.25. Salinities of 3 to 4 dS m^{-1} indicate the field was well leached in the past. The chloride concentrations at field water content ranged from 12 to 17 mol m^{-3}. These concentrations correspond to leaching fractions ranging from 0.22 to 0.31 based on a chloride concentration in the irrigation water of 3.7 mol m^{-3}. R_{Na} values varied from 5 to 6 and are consistent with Colorado River water and a leaching fraction of about 0.3. So is a ratio of calcium to magnesium of about 2:1. However, the sulfate values for the lower portions of the profile are too high indicating the possible presence of gypsum in the soil profile. The activity product of calcium times sulfate in the soil water obtained from the vacuum extractors, in most instances, equalled that expected for a saturated gypsum solution. There are two sources of gypsum: 1) native gypsum present in these soils in their virgin state or 2) the calcium and sulfate in the irrigation water which will precipitate as gypsum whenever the leaching fractions drops below 0.1.

Soil salinity was initially quite uniform among the different leaching treatments with soil depth (see Tables B-2 to B-6); only the flood check exhibited an increasing salinity with depth. Replicates II5 and II20 were the most saline which was also evident in the soil water extracts obtained with the vacuum extractors (Tables B-7, B-8, and B-9) during the experiment.

No soil samples were taken at the end of the experiment because of the accidental application of 150 mm of flood water the first week of October 1978.

Soil Chloride Distribution

The average soil water chloride concentration in December 1976 for replicate II20 of the experiment and for the flood check are given in Table 30. The maximum concentrations, values at the bottom of the root zone, occurred in the 1.5- to 2.0-m depth interval where the average concentration was 26 mol m^{-3} for both treatments. This chloride value indicates a leaching fraction of 0.14 ($L = Cl_i/Cl_d = 3.7/26$). Based on this maximum concentration, the relative water loss distributions were calculated using Eq. 2

TABLE 29. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES AT THE BEGINNING OF THE LEACHING TREATMENT

Soil Depth	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
m	dS m^{-1}	(mol $m^{-3})^{1/2}$	kg kg^{-1}	mol m^{-3}							
				Leaching Fraction Treatments							
0-0.3	2.4	5.5	0.42	4.3	2.6	13.9	0.3	2.8	8.3	0.6	1.7
	(0.8)*	(0.9)	(0.03)	(2.3)	(1.2)	(4.7)	(0.1)	(0.6)	(4.1)	(3.4)	(0.8)
0.3-0.6	3.4	5.6	0.42	7.1	3.7	18.6	0.4	1.9	12.8	12.6	1.0
	(1.0)	(1.1)	(0.04)	(2.2)	(1.7)	(6.8)	(0.2)	(0.6)	(5.4)	(2.0)	(0.8)
0.6-0.9	3.2	5.7	0.48	5.6	3.3	19.6	0.4	2.0	12.3	11.0	0.6
	(1.3)	(1.3)	(0.05)	(2.6)	(1.8)	(11.1)	(0.3)	(0.3)	(10.6)	(6.8)	(0.4)
0.9-1.2	3.3	5.0	0.53	6.2	3.5	20.5	0.4	1.8	14.2	9.9	0.4
	(1.3)	(1.6)	(0.08)	(3.9)	(2.2)	(11.9)	(0.4)	(0.9)	(8.5)	(3.9)	(0.2)
1.2-1.5	3.4	5.1	0.56	5.9	3.0	20.6	0.4	1.8	13.9	8.7	0.4
	(1.8)	(1.9)	(0.06)	(4.1)	(2.6)	(11.5)	(0.3)	(0.7)	(8.9)	(2.3)	(0.3)
				Flood Check							
0-0.3	2.2	5.1	0.40	3.8	2.1	12.2	0.2	1.6	7.7	5.2	2.0
	(0.6)	(0.8)	(0.04)	(2.1)	(1.1)	(3.3)	(0.1)	(0.3)	(4.4)	(1.6)	(0.8)
0.3-0.6	2.4	5.9	0.42	4.0	2.6	14.7	0.2	1.2	9.2	7.4	1.0
	(0.6)	(0.9)	(0.08)	(1.8)	(1.2)	(3.7)	(0.1)	(0.3)	(3.3)	(2.9)	(0.4)
0.6-0.9	2.6	5.8	0.49	4.7	3.0	14.9	0.2	1.3	10.6	7.1	1.0
	(0.8)	(0.9)	(0.06)	(3.2)	(1.8)	(3.0)	(0.2)	(0.3)	(5.7)	(3.3)	(0.3)
0.9-1.2	2.9	5.8	0.53	5.4	3.6	16.5	0.2	1.3	12.5	7.8	1.0
	(0.8)	(1.1)	(0.04)	(3.6)	(1.7)	(3.3)	(0.2)	(0.4)	(6.5)	(2.9)	(0.6)
1.2-1.5	3.2	6.1	0.55	6.4	4.5	18.5	0.3	1.2	15.5	7.5	0.8
	(1.0)	(1.4)	(0.06)	(4.5)	(2.5)	(4.6)	(0.2)	(0.4)	(9.2)	(2.8)	(0.4)

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* Standard deviation assuming normal distribution.

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TABLE 30. RELATIVE WATER UPTAKE DISTRIBUTIONS FOR ALFALFA BASED ON SOIL CHLORIDE CONCENTRATIONS IN DECEMBER 1976 FOR THE 20% LEACHING TREATMENT AND THE FLOOD CHECK

Soil Depth	20% Leaching Treatment		Flood Check	
	Soil Chloride Concentration	Relative Water Uptake	Soil Chloride Concentration	Relative Water Uptake
m	mol m^{-3}		mol m^{-3}	
0.3	11.1	0.78	6.8	0.53
0.6	16.5	0.90	8.6	0.66
0.9	19.8	0.95	12.6	0.82
1.2	23.0	0.98	21.1	0.96
1.5 to 2.0	26.0	1.00	26.0	1.00

(p. 32). The 20% leaching treatment had a shallower water uptake distribution than the flood check. About 90% of the water uptake occurs above a soil depth of 0.6 m for the 20% leaching treatment; the corresponding depth for the flood check is about 1.1 m.

Soil Salinity

The time course of average *in situ* salinity for all treatments is given in Fig. 30. In the leaching treatments, the salinity at 0.3 m declined during 1975 while it increased at deeper depths. After a period of relative stability in 1976, rapid fluctuation occurred in 1977 with an overall decline evident in the 0.3- and 0.6-m depths. In contrast to these trends, those in the flood irrigated field declined during 1975 to mid 1976 followed by a slow but general increase afterward. In addition, the levels of salinity in the flood field at 0.3 and 0.6 m during 1975 and 1976 were lower than at the corresponding time and depths in the leaching treatments. In 1978, the salinity levels at all depths in the flood irrigated field were comparable to those in the 10% leaching treatment. These trends are consistent with initial salinity levels and differences (or changes) in water management.

Initial average (n = 24) salinity levels (Nov 1974) for the leaching treatments were 8, 6, 7 and 7 dS m^{-1} for soil depths of 0.3, 0.6, 0.9 and 1.2 m respectively. This relatively constant salinity with depth is consistent with the chemical properties reported in Table 29 and corresponds to a L of about 0.14 (Table 3). Consequently, salinity levels at 0.3 m in all leaching treatments were expected to decline initially and to increase at

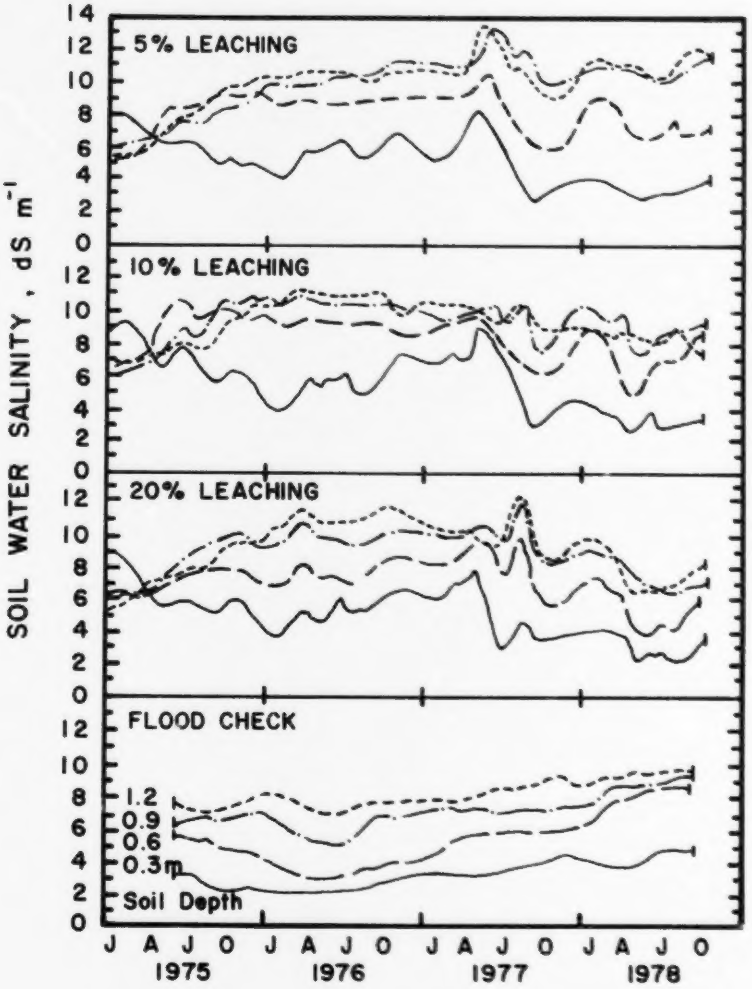

Fig. 30. Time course of the average *in situ* soil salinity during the alfalfa experiment.

greater depths for the 5 and 10% leaching treatments. The pronounced changes which occurred in 1977 reflect a major change in the water application method. In May 1977, the amount of water applied in each irrigation was increased from 6 to 70 mm which resulted in the marked decline in salinity at the 0.3- and 0.6-m depths.

Differences in salinity distributions and levels between flood irrigation and the leaching treatments are also believed to be a consequence of water management. The in situ salinities in the flood check are much lower in the shallow portion of the profile reflecting the application of 150 mm of water per irrigation, rather than 6 mm, and the tendency for a crop to develop a deep water uptake distribution pattern if irrigated infrequently. The salinities showed a steady rise at all depths after mid 1976. This rise was probably caused by the rancher wishing to become more efficient in his water use.

The average leaching fraction for each treatment during 1978 can be calculated from the average soil water salinity value at soil depths of 0.9 and 1.2 m. Such calculations were made, using the salinity near the bottom of the root zone (Fig. 31) and taking account of salt precipitation. The relation between σ and L was illustrated in Table 3. The result of these calculations, for the last year of the experiment, resulted in estimates for L of 0.08, 0.11, 0.13 and 0.11 for the 5, 10 and 20% leaching treatments and the flood check, respectively.

Water Table

Unlike the citrus experiment, a relatively shallow water table was present in the alfalfa experiment. From mid 1975 until mid 1978, the depth of the water table below the soil surface was measured periodically at six locations around the periphery of the leaching experiment. Because the coefficient of variation of the six measurements was always less than 0.2, only the mean water table depth as a function of time is given in Fig. 32. The water table remained relatively stable between 2.5 and 3.0 m below the soil surface throughout 1975 and 1976. During 1977, the water table dropped slowly until in mid 1978 it was below the bottom of our observation wells at a depth of 4.6 m. This gradual drop was no doubt caused by the cessation of citrus irrigation; the trees on the mesa immediately to the south of our experiment were removed in 1976.

With maximum soil salinity values in the experiment above a soil depth of 1.5 m some water may have been withdrawn by the alfalfa from the water table in the 5 and 10% leaching treatments. Neither maximum values of soil salinity (see Fig. 31) nor chloride concentration (see Table 30) can be verified for the 20% leaching treatment or the flood check; thus, little, if any, water was extracted from the water table by these treatments.

Hydraulic Properties

The relationship between hydraulic conductivity and soil water matric potential for Indio fine sandy loam is given in Fig. 33. These data were

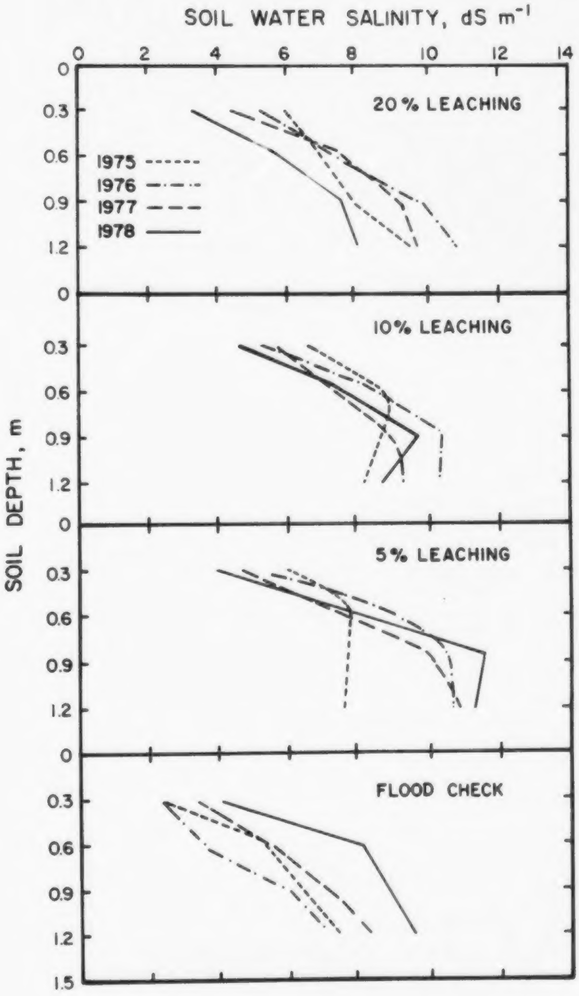

Fig. 31. Time-averaged soil salinity distributions by year during the alfalfa experiment.

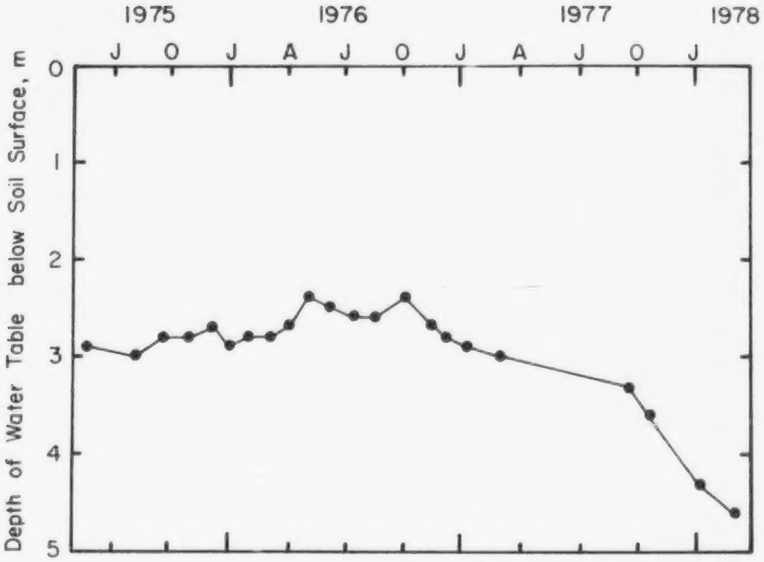

Fig. 32. Average depth of the water table below the soil surface during the alfalfa experiment.

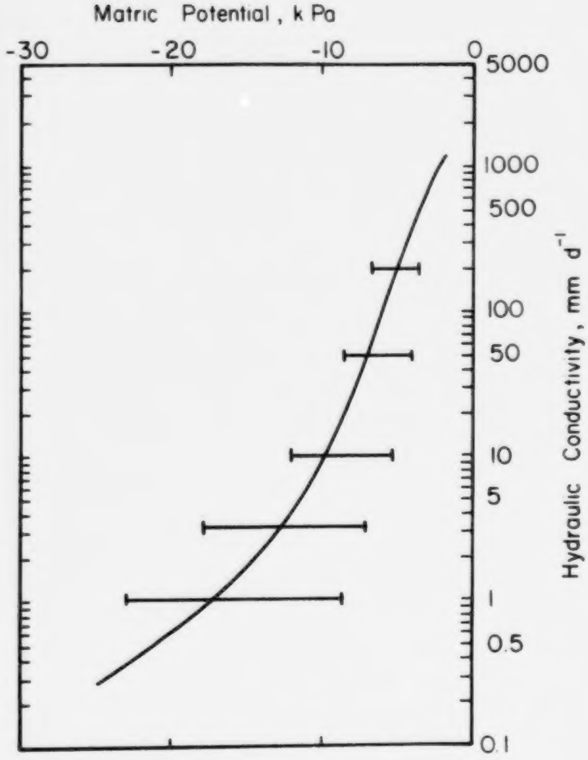

Fig. 33. Relationship between soil water matric potential and hydraulic conductivity for Indio fine sandy loam.

obtained from three 0.9-m-deep undisturbed soil columns taken in the fall of 1974. The horizontal lines in the figure indicate the standard error in each measured point.

Soil Hydraulic Head

After converting the 36 tensiometers installed in each of the three leaching treatments from automatic readings with pressure transducers to mercury manometers for manual readings, few problems were encountered. To illustrate trends among treatments with soil depth, hydraulic heads were averaged for all tensiometers at a given depth in each leaching treatment. Fig. 34 shows the mean hydraulic heads, averaged for 1976, 1977, and 1978, for the three leaching treatments. For readings taken by the automatic reading system in 1975, the reader is referred to the Interim Report (U.S. Salinity Laboratory Staff, 1977).

Unlike the citrus experiment, the hydraulic head remained fairly stable throughout the year. Differences between treatment replications were also small except for the 5% leaching treatment. As previously reported, replication I5 gave consistently lower hydraulic heads than II5. In 1976, values for II5 were close to those for 10% leaching while values for I5 were as much as 3 m lower. This difference gradually disappeared and by 1978 the mean values for the two replications were close. As an illustration, the mean hydraulic heads in 1976 for the 0.9-m soil depth were -5.8 and -2.7 m for replicates I5 and II5, respectively. In 1978, the respective values were -3.7 and -3.2 m.

The hydraulic head data show an upward flow of soil water on the average between soil depths of 1.0 and 1.5 m for the 5 and 10% leaching treatments in two of the three years reported. A downward gradient at all soil depths monitored existed for the 20% leaching treatment for all three years. This upward gradient is probably caused by movement of water up from the water table (see Fig. 32). These data would suggest that the 5 and 10% leaching treatments were underirrigated, at least part of the time, and would suggest lower than desired leaching fractions.

Suction Lysimeter Volumes and Salt Concentrations

With time, the soil filling the suction lysimeters settled below the average ground level, allowing surface water to flow into them from the surrounding area. As a result, the volume of water collected was in error and is not reported. For suction lysimeters of this design to function properly, a surface barrier with dimensions equal to those of the subsurface lysimeter must be installed and monitored to permit only the water applied over the lysimeter to enter it. Because of the frequent traffic from harvesting, we had hoped, incorrectly, that the surface barrier was not needed.

Vacuum Extractor and Suction Lysimeter Volumes and Salt Concentrations

The time course of accumulative volumes of leachate collected from the

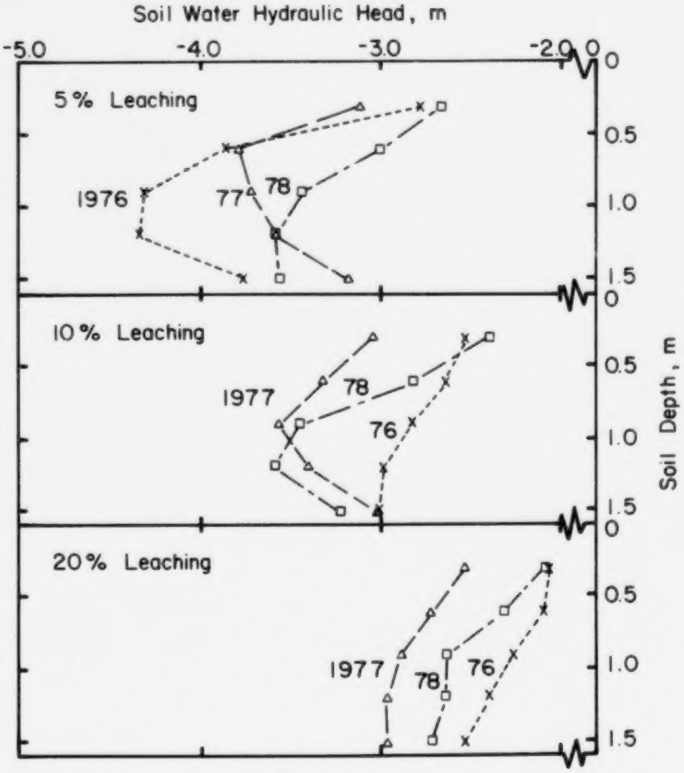

Fig. 34. Mean hydraulic head distribution for the three leaching treatments in the alfalfa experiment for 1976, 1977, and 1978.

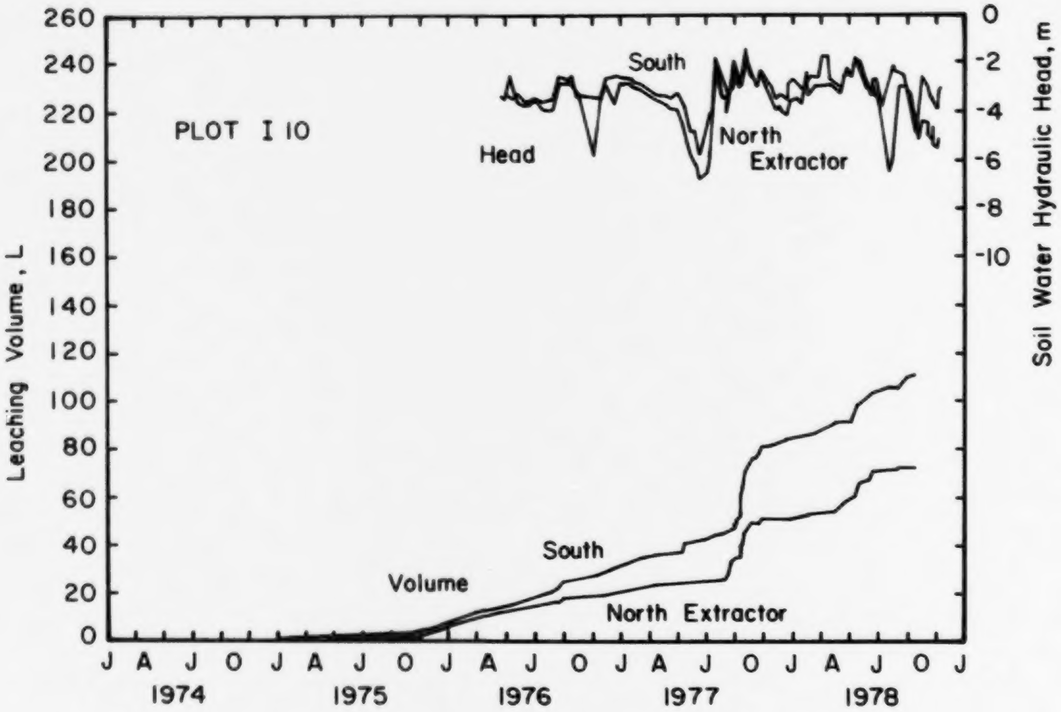

Fig. 35a. Volume of leachate and average soil water hydraulic head for the two extractors (north and south locations, see Fig. 29) in plot I10.

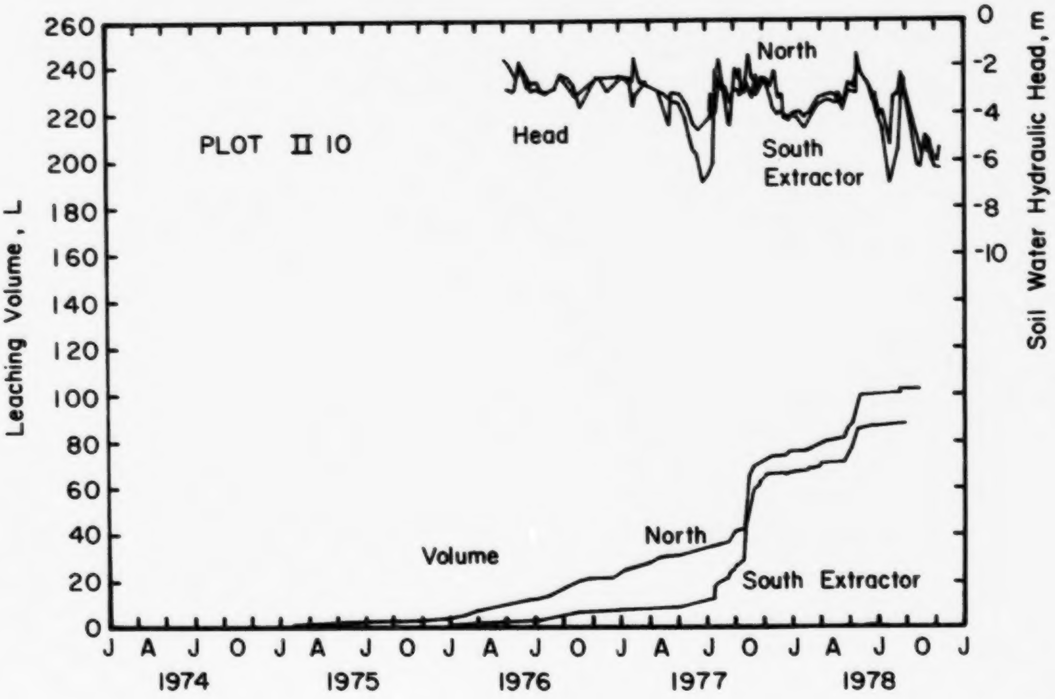

Fig. 35b. Volume of leachate and average soil water hydraulic head for the two extractors in plot II10.

two vacuum extractors in each of the two instrumented replicates for the 10% leaching treatment is given in Fig. 35. The hydraulic heads measured with tensiometers just above each extractor are also shown. Time courses for the 5 and 20% leaching treatments are given in Figs B-1 and B-2 in the Appendix. As was the case with the extractors in the citrus experiment, the hydraulic head generally had to exceed -2 m for leachate to be collected. Exceptions to this are the extractors in Plot I5. The hydraulic head above this extractor did not rise to -2 m until July 1977. By this time, over 15 liters of extract had already been collected from the south extractor, and over 4 liters from the north extractor. The volume of the leachate collected from all extractors increased considerably in July and August of 1977 when extra water was applied to compensate for a pump failure the previous month.

There is a question how much influence the water table had on the volume of leachate collected by the extractors. The extractors, however, were located in the western half of the field and the water table depth of the monitoring site nearest to the extractors never rose closer than 3 m to the soil surface for the entire experiment. The closest the water table came to the soil surface at any site was 2 m, during the summer and fall of 1976. The fact that this time period does not correspond to an increase in flow from the extractors is evidence that the water table had no significant influence on the leachate volume collected. The period of greatest flow from the extractors was one year later, when the water table had fallen substantially.

The volumes of leachate from these extractors followed more closely those expected than did those in the citrus experiment. Discrepancies did occur between duplicate extractors at some sites, however.

Table 31 gives the calculated leaching fractions for the last 3 years of the experiment based on the electrical conductivity (σ), chloride concentration (Cl), and volume (V) of the leachate collected from each vacuum extractor in the instrumented plots. Data for electrical conductivity and chloride concentration during 1975 are not presented because of the time delay in changing the salt concentration in the soil profile resulting from prior irrigation management. Leaching fractions based on volume of leachate in 1975, however, were consistent with the quantity of irrigation water supplied.

The leaching fraction calculated for each treatment by the three different techniques are in good agreement. For the 5% leaching treatment, average values for leaching fraction from 1976 to 1978 range from 0.040 to 0.077, and averaged 0.063 for all six means given in Table 31. The range was from 0.058 to 0.142 for the 10% leaching treatment with an overall average of 0.090. The overall average for 20% leaching was 0.128 with a range of 0.042 to 0.234.

The chemical composition of most of the constituents in the leachates from the individual extractions are given in the Appendix (Tables B-7, B-8, and B-9). Significant differences between replicate plots present in 1975 persisted to the end of the experiment. To a lesser extent, differences

TABLE 31. AVERAGE LEACHING FRACTIONS BY YEAR BASED ON ELECTRICAL CONDUCTIVITY (σ), CHLORIDE CONCENTRATION (Cl), AND DRAINAGE VOLUME (V) MEASUREMENTS FROM THE NORTH (n) AND SOUTH (s) VACUUM EXTRACTORS IN EACH INSTRUMENTED PLOT OF THE ALFALFA EXPERIMENT

Year	σ_n*	σ_s	Cl_n	Cl_s	V_n	V_s	σ_n	σ_s	Cl_n	Cl_s	V_n	V_s
5% Leaching												
			Plot I5						Plot II5			
1976	0.095	0.100	0.051	0.059	0.009	0.028	0.057	0.077	0.060	0.053	0.085	0.091
1977	0.056	0.082	0.026	0.051	0.045	0.089	0.057	0.095	0.064	0.098	0.088	0.077
1978	0.059	0.070	0.027	0.042	0.032	0.067	0.056	0.096	0.062	0.129	0.041	0.019
MEAN	0.077		0.040		0.047		0.073		0.072		0.068	
10% Leaching												
			Plot I10						Plot II10			
1976	0.074	0.059	0.050	0.047	0.035	0.062	0.134	0.126	0.102	0.094	0.055	0.020
1977	0.080	0.064	0.059	0.073	0.058	0.100	0.156	0.142	0.158	0.156	0.100	0.119
1978	0.068	0.070	0.049	0.091	0.050	0.062	0.146	0.149	0.206	0.217	0.064	0.047
MEAN	0.069		0.058		0.062		0.142		0.140		0.072	
20% Leaching												
			Plot II20						Plot III20			
1976	0.095	0.110	0.045	0.050	0.119	0.086	0.189	0.157	0.094	0.052	0.046	0.050
1977	0.080	0.093	0.038	0.041	0.095	0.166	0.254	0.200	0.121	0.091	0.199	0.226
1978	0.088	0.109	0.036	0.043	0.147	0.244	0.360	0.243	0.268	0.175	0.138	0.169
MEAN	0.096		0.042		0.144		0.234		0.108		0.146	

* Leaching fractions were corrected for salt precipitation by using the relationship between electrical conductivity and leaching fraction given in Table 3.

between the two extractors in a single plot also tended to persist. The changes in chemical composition that occurred during the experiment were often unexpected. For example, the expected values for R_{Na} and σ in the 10% leaching treatment were 12 $(\text{mol m}^{-3})^{1/2}$ and 9.5 dS m^{-1} (see Table 3). Even though the values measured early in the experiment exceeded those expected at steady state in plot I10, they continued to rise (Table B-8). Similar unpredicted trends are evident in some extractors for the 20% leaching treatment as can be seen by comparing the values measured (Table B-9) with those expected at steady state (Table 3).

The composition data for plot III20 (Table B-9) are probably influenced by the need to repair the extractors in 1976. Because a pressure regulator failed in June of 1976, the pillow pressure holding the extractors against the soil rose to over 300 kPa, breaking the vacuum line to the suction candles within the extractor. The holes dug between the manhole and the extractors to repair this damage were not properly backfilled, allowing irrigation water to be channeled directly to the extractors in 1978; this probably accounts for the large drop in σ and individual ion concentrations.

Water Use

The average daily water applications, rainfall included, are given in Fig. 36 for the three leaching treatments and the flood check by month. The average daily applications applied to each treatment for each month of the experiment are given in Fig. B-3 of the Appendix. Less water was applied to the flood check by the farmer than was applied to the experimental plots in the summer, while more was applied in the spring. On an annual basis over the 4-year period (Table 32), a little less water was applied to the flood

TABLE 32. ANNUAL DEPTHS OF WATER APPLIED (IRRIGATION PLUS RAINFALL) FOR EACH TREATMENT OF THE ALFALFA EXPERIMENT. DEPTHS ARE GIVEN IN mm

Year	Leaching Treatment			Flood Check
	5%	10%	20%	
1975	1980	2080	2260	2190
1976*	1540	1620	1770	2000
1977	2130	2190	2370	2190
1978**	1730	1820	2060	1650
MEAN	1840	1930	2120	2010

* Alfalfa removed in August and replanted the last of September.

** Alfalfa experiment was terminated the first week in October so that a fall crop could be planted.

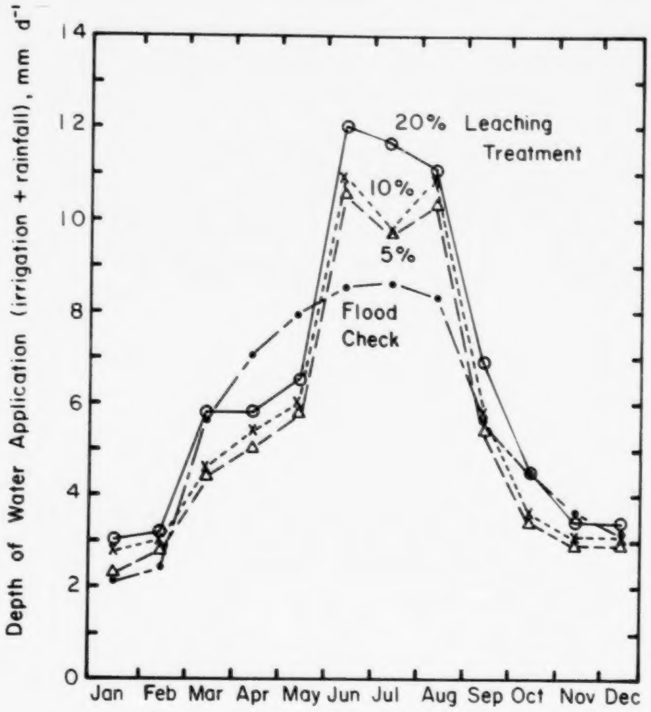

Fig. 36. Average daily water applications (irrigation plus rainfall) for the three leaching treatments and the flood check by month during the 4-year study on alfalfa.

check (2010 mm) than to the 20% leaching treatment (2120 mm). Less water was applied in 1976 and 1978 than the remaining 2 years because the alfalfa was removed at the end of July in 1976 and replanted in October and because the experiment was terminated in October 1978 because of the accidental flooding of the experiment. Rainfall, totalled per month in Table B-10, averaged 144 mm annually and was added to the irrigation application values.

As with citrus, ET can be estimated by subtracting the planned leaching depth from the actual depth of water applied. This estimate of daily ET for alfalfa, computed on a monthly basis, is presented in Fig. 37. For comparison, the average daily ET calculated from the five predictive equations presented for citrus is also given. The meteorological data required for these calculations are given in Table B-11 and Table A-5. The crop coefficient, k_c, was taken as 1.1 (Doorenbos and Pruitt, 1975). The best estimate of the average annual ET is 1930 mm (Table 33). This value compares favorably with other measured values of ET for alfalfa in the general area. Our irrigation factor, k_i, for alfalfa is 0.75. With the pan coefficient, k_p, of 0.7, the crop coefficient, k_c, is 1.07; very close to the published value of 1.1.

Root Distribution

Measurements were made in September and October 1978 to determine the root distribution pattern and to determine if there were differences among treatments. In September, the mass of roots in a 0.01 m^3 volume of soil was determined at 15-cm depth intervals to a depth of 1.5 m in the 5% leaching treatment and the flood check. In October, samples were taken at the same increments to a depth of 1 m in the 5 and 20% leaching treatments and the flood check. The root density distribution for each of these sets of measurements is given in Fig. 39. The values are reported as the means of fresh roots divided by the volume of the soil sample. The number of samples was limited (2 for each data point in Fig. 39); however, below a depth of 0.2 m, there did not appear to be a significant treatment effect on root density. The mean root density as a function of soil depth is given in Table 34; also given in the table is the relative root distribution. Compared with the relative water uptake distribution based on soil-water chloride measurements (Table 30), the root mass appeared to be more shallow. One may argue that root samples were not taken to the same soil depth and thus the relative root distribution is skewed because roots deeper in the profile were ignored. If we assume a root density of 0.2 kg m^{-3} (as found at the 0.90- to 1.05-m soil depth) down to a depth of 2.0 m, the adjusted relative root distribution (so listed in Table 34) is very similar to the calculated relative water uptake distribution for the 20% leaching treatment in Table 30.

Crop Yield

The alfalfa yields for 1975 and 1976 were given in the Interim Report (U.S. Salinity Laboratory Staff, 1977). Yields for the three leaching treatments and the flood check are given for each replication in Tables 35 and 36 for 1977 and 1978, respectively. Total yields, averaged among replications, for the 5, 10, and 20% leaching treatments were 21.0, 21.4, and 22.0 Mg/ha in 1977 and 22.5, 23.0 and 23.1 Mg/ha in 1978, respectively.

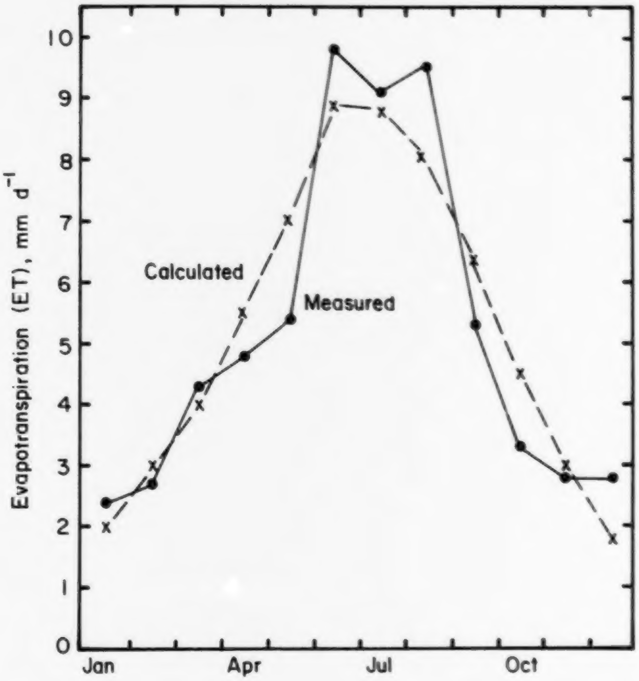

Fig. 37. Evapotranspiration computed from measured water applications and desired leaching fractions (measured) and calculated from various predictive equations (calculated) for alfalfa in southwest Arizona.

TABLE 33. COMPARISON OF EXPERIMENTALLY MEASURED VALUES OF EVAPOTRANSPIRATION (mm d^{-1}) OF ALFALFA WITH CALCULATED VALUES FROM FIVE PREDICTIVE EQUATIONS

Month	Experimentally Measured			Calculated Based On					Mean Measured[3]	Mean Calculated
	Tacna Ariz.	Brawley[1] Calif.	Phoenix[2] Ariz.	Pan Evaporation	Radiation	Jensen Haise	Blaney Criddle	Modified Penman		
Jan	2.4	2.1		2.0	2.1	1.6	2.4	2.1	2.2	2.0
Feb	2.7	2.3		3.0	3.1	2.4	3.1	3.4	2.5	3.0
Mar	4.3	4.7	4.9	4.0	4.3	3.4	4.0	4.4	4.5	4.0
Apr	4.8	5.8	6.4	5.8	6.1	5.2	5.0	5.6	5.3	5.5
May	5.4	7.8	8.2	6.9	7.3	6.9	6.7	7.0	6.6	7.0
June	9.8	9.7	9.2	9.4	8.1	9.0	8.6	9.4	9.8	8.9
July	9.1	9.1	8.8	9.1	7.4	9.1	9.2	9.2	9.1	8.8
Aug	9.5	7.4	7.4	8.0	7.2	8.7	8.6	8.2	8.4	8.1
Sep	5.3	7.0	7.8	6.4	5.5	6.5	7.2	6.3	6.1	6.4
Oct	3.3	4.6	4.6	4.3	4.2	4.2	5.2	4.4	4.0	4.5
Nov	2.8	3.2	3.0	3.1	2.9	2.4	3.3	3.2	3.0	3.0
Dec	2.8	1.6		1.8	1.9	1.4	2.1	2.0	2.2	1.8
Annual (mm)	1900	1990	1890	1940	1830	1850	1990	1990	1940	1920

---

[1] Unpublished data.

[2] Erie, L. J., O. F. French, and K. Harais. 1965. "Consumptive use of water by crops in Arizona", Univ. of Arizona Agr. Exp. Sta. Tech. Bull. 169, 44 p.

[3] Phoenix data are not included in the mean values.

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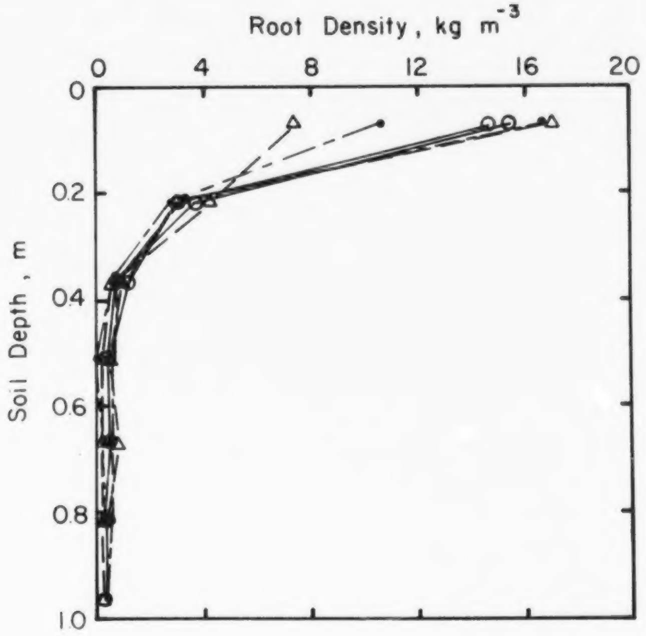

Fig. 38. Root distribution with soil for the 5% leaching treatment in September and October (Δ), the 20% leaching treatment in October (O), and the flood check in September and October 1978 (·).

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TABLE 34. RELATIVE DISTRIBUTION OF ALFALFA ROOTS AS A FUNCTION OF SOIL DEPTH BASED ON ROOT DENSITY MEASUREMENTS

Soil Depth m	Root Density kg m^{-3}	Relative Root Distribution	Adjusted Relative Root Distribution
0 to 0.15	13.9	0.71	0.67
0.15 to 0.30	3.4	0.88	0.83
0.30 to 0.45	0.9	0.93	0.88
0.45 to 0.60	0.4	0.95	0.89
0.60 to 0.75	0.5	0.97	0.92
0.75 to 0.90	0.3	0.99	0.93
0.90 to 1.05	0.2	1.00	0.94
1.05 to 1.95	0.2*		1.00

* Assumed root density for comparison with relative water uptake based on soil chloride.

Analysis of variance indicated no significant differences among the three leaching treatments.

As in 1975 and 1976, the yields of all treatments gradually increased with each cutting until early summer as the density of the alfalfa stand increased and then decreased during late summer as typical in alfalfa production. Production in 1978 exceeded 1977, only because one additional cutting was made early in the season.

Yields from the second alfalfa planting were substantially higher than those from the first indicating that the problems of weeds and soil compaction in the experimental treatments in 1975 and 1976 were overcome. Combined yields of the 1977-78 crop exceeded that of the 1975-76 crop by 31%. The second planting also produced much better relative to the flood check than did the first planting. The yields were smaller the first few cuttings in 1977 as the young stand matured, became comparable the last half of the season and then outyielded the flood check in 1978. Mean yields of the experimental plots (21.5 Mg/ha) were lower than that of the flood check (25.7 Mg/ha) in 1977 but higher in 1978 (22.9 vs. 20.8 Mg/ha).

TABLE 35. ALFALFA YIELD (Mg ha^{-1})* FOR EACH REPLICATION OF THE LEACHING TREATMENTS AND FOR THREE LOCATIONS WITHIN THE FLOOD CHECK FOR THE 1977 SEASON

Leaching Treatment	Replication 1	2	3	4	5	Average Yield
		1st Cutting -- 03/22/77				
5%	3.6	2.4	2.3	2.7	2.3	2.7
10%	3.0	2.6	3.5	3.8	2.0	3.0
20%	2.8	3.2	3.0	3.4	3.2	3.1
Flood	3.3	4.7	4.9			4.3
		2nd Cutting -- 04/27/77				
5%	2.5	2.9	2.5	3.5	2.2	2.7
10%	2.6	3.1	3.0	3.1	3.2	3.0
20%	3.0	2.6	2.9	3.1	2.9	2.9
Flood	4.1	3.6	4.1			3.9
		3rd Cutting -- 5/31/77				
5%	3.5	3.6	3.2	3.0	3.5	3.4
10%	3.9	3.6	3.4	3.5	2.9	3.4
20%	3.8	3.8	3.5	3.2	3.3	3.5
Flood	5.0	4.1	4.8			4.6
		4th Cutting -- 7/1/77				
5%	4.0	4.2	4.4	4.0	4.8	4.3
10%	4.4	3.9	3.7	4.3	4.0	4.0
20%	3.4	4.1	3.7	4.3	4.3	4.0
Flood	4.7	3.6	4.6			4.3
		5th Cutting -- 7/29/77				
5%	4.4	4.1	3.4	2.6	3.4	3.6
10%	3.2	3.7	3.2	3.8	3.9	3.6
20%	4.2	3.5	3.7	3.4	3.7	3.7
Flood	4.6	4.2	3.4			4.1
		6th Cutting -- 8/31/77				
5%	2.2	2.4	1.9	2.2	1.2	2.0
10%	2.0	2.6	2.1	2.0	1.0	1.9
20%	2.4	2.4	2.2	1.9	1.6	2.1
Flood	2.5	1.9	2.3			2.2
		7th Cutting -- 10/25/77				
5%	3.0	2.4	2.9	2.0	1.8	2.4
10%	2.3	2.7	2.4	2.6	2.2	2.4
20%	2.6	3.3	2.8	2.6	2.3	2.7
Flood	2.4	2.1	2.5			2.3

* 1 Mg ha^{-1} = 0.446 ton acre^{-1}.

TABLE 36. ALFALFA YIELD (Mg ha^{-1})* FOR EACH REPLICATION OF THE LEACHING TREATMENTS AND FOR THREE LOCATIONS WITHIN THE FLOOD CHECK FOR THE 1978 SEASON

Leaching Treatment	Replication 1	2	3	4	5	Average Yield
			1st Cutting -- 1/27/78			
5%	1.7	1.7	1.5	1.5	1.7	1.6
10%	2.1	2.0	1.9	1.7	1.4	1.8
20%	2.3	1.9	1.8	1.8	1.7	1.9
Flood	1.6	1.3	1.5			1.5
			2nd Cutting -- 3/20/78			
5%	2.5	2.5	2.4	2.0	2.0	2.3
10%	3.0	2.4	2.7	2.2	1.6	2.4
20%	2.5	2.5	2.4	2.4	2.1	2.4
Flood	2.6	1.8	2.2			2.2
			3rd Cutting -- 4/26/78			
5%	3.4	3.2	3.3	3.1	2.9	3.2
10%	3.4	3.1	3.0	3.1	2.8	3.1
20%	3.6	3.4	3.3	3.2	3.1	3.3
Flood	3.2	2.6	3.3			3.0
			4th Cutting -- 6/1/78			
5%	4.3	4.1	4.0	4.1	3.5	4.0
10%	4.0	4.0	4.3	3.7	3.4	3.9
20%	3.8	4.2	4.0	4.0	3.8	3.9
Flood	3.9	3.6	4.0			3.9
			5th Cutting -- 6/29/78			
5%	4.1	4.3	3.7	3.7	3.4	3.9
10%	4.3	3.8	3.9	3.9	3.6	3.9
20%	3.5	3.9	3.8	3.7	3.4	3.7
Flood	4.0	3.8	3.3			3.7
			6th Cutting -- 7/31/78			
5%	2.6	3.7	3.5	3.5	2.9	3.2
10%	2.9	3.6	3.9	3.4	3.4	3.4
20%	3.7	3.0	3.2	3.2	3.0	3.2
Flood	2.8	2.6	2.5			2.6
			7th Cutting -- 9/5/78			
5%	2.8	2.8	3.1	3.0	2.4	2.8
10%	2.9	2.7	2.8	3.1	3.1	2.9
20%	2.9	2.8	2.9	3.2	2.6	2.9
Flood	2.5	2.1	2.0			2.2
			8th Cutting -- 10/5/78			
5%	2.0	1.8	1.3	1.5	1.5	1.6
10%	2.0	1.5	1.6	1.7	1.3	1.6
20%	2.3	1.8	1.5	1.8	1.5	1.8
Flood	1.4	1.2	1.1			1.7

* 1 Mg ha^{-1} = 0.446 ton $acre^{-1}$.

Yields from the experimental plots indicated no significant differences among leaching treatments during any of the 4 crop years. The data indicate that as little as 5% leaching, if attainable with typical on-farm management, would result in yields equally as large as those with 20% leaching but with a substantial savings in water.

Shoot Analysis

Data for the samples taken in 1975 were given in the 1977 Interim Report. No analyses were made in 1976. Results of the analyses made on the 1977 and 1978 samples are summarized in Tables 37 and 38, respectively, and compared with published tissue analyses to evaluate nutrient status (Chapman, 1967). Levels of Ca appeared low and S somewhat high both years. This was also true in 1975. Nitrogen, P, and K concentrations were similar in 1975 and 1977 but increased in 1978; P increased from low to adequate levels, K from adequate to high levels. However, there was no visual evidence of any nutritional problem. All other nutrient elements were within normal concentration ranges. Na levels were normal and substantially lower than found in 1975. No important differences in mineral contents were noted among leaching treatments and generally they were similar to those of the flood check samples.

TABLE 37. MINERAL COMPOSITION OF ALFALFA SHOOTS SAMPLED OCT 4, 1977

Element	(unit)	Adequate Range*	Leaching Treatment 5%	10%	20%	Flood Check
N	g/kg	---	34	36	35	35
P	mmol/kg	80-160	64	68	69	62
K	"	300-650	700	710	730	650
Ca	"	420-620	345	340	335	350
Mg	"	> 80	110	115	110	110
Na	"	5-100	61	65	79	40
Cl	"	---	250	240	260	210
S	"	60-100	140	130	130	120
B	Mg/kg	20-200	57	55	62	58
Fe	"	---	91	94	96	89
Mn	"	> 15	32	33	36	30
Zn	"	20-50	29	31	28	27
Cu	"	5-16	13	13	13	14

* Adequate range based on data tabulated by Chapman (1967).

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TABLE 38. MINERAL COMPOSITION OF ALFALFA SHOOTS SAMPLED SEPT 20, 1978

Element	(unit)	Adequate Range*	Leaching Treatment			Flood Check
			5%	10%	20%	
N	g/kg	---	50	46	47	50
P	mmol/100g	80-160	118	113	112	122
K	"	300-650	1010	1020	1010	920
Ca	"	420-620	370	355	360	380
Mg	"	> 80	155	160	150	140
Na	"	5-100	63	50	52	60
Cl	"	---	360	350	350	290
S	"	60-100	180	175	180	175
B	Mg/kg	20-200	63	59	59	61
Fe	"	---	92	89	90	102
Mn	"	> 15	30	29	30	34
Zn	"	20-50	41	41	38	41
Cu	"	5-16	16	16	16	16

* Adequate range based on data tabulated by Chapman (1967).

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DISCUSSION

As with the citrus experiment, the objective of the alfalfa experiment was to determine to what extent the amount of salt in irrigation return flows could be reduced.

Whereas the citrus experiment concerned a perennial tree crop on coarse textured soil, the alfalfa was seeded on relatively fine textured soil. The experimental irrigation system and planned management scheme were found to be not fully compatible with the other cultural practices. Thus, as detailed in the Interim Report, early results did not meet expectations. However, after changes in the irrigation schedule were instituted and the alfalfa was replanted, useful results were obtained.

Evapotranspiration and Leaching Fraction

Although differential water applications were explicitly maintained throughout the experiment, the various measures of leaching fraction attained indicate that the differences in leaching were not as large as planned. Based on salt sensor data (p.97), L = 0.08, 0.11 and 0.13 for the three treatments, and 0.11 for the flood check. Chloride data taken in 1976 yielded L = 0.14 for the high leaching treatment. The solutions collected in the extractors gave a range of values with means L = 0.063, 0.090 and 0.128 for the low, medium and high treatments, using electrical conductivity, chloride concentration and volume measurements (p. 107).

Some additional uncertainty was introduced because the crop apparently used some water from the shallow water table. Both the salt sensor data and the hydraulic head data indicate upward flow in the 5 and 10% leaching treatments but not the 20% treatment. One may conclude that the plots were irrigated so that there were definite differences in leaching, but the actual leaching fractions attained were probably somewhat less than those planned.

During the experiment, the farmer-irrigated flood check received more water than the 10% treatment but less than the 20% treatment.

Determination of the evapotranspiration (ET) is complicated by the timing of various operations. The alfalfa was removed in August 1976 for replanting and the experiment was terminated in October 1978. Thus, full-year water consumption records were obtained only in 1975 and 1977.

Using the water application data and assuming the planned leaching fractions; using experimental data from Phoenix, Arizona and Brawley, California; and calculating evapotranspiration from various equations, yielded eight estimates for crop water use. The best, somewhat arbitrary, estimate derived from these calculations is that annual ET for alfalfa was 1930 mm (Table 33).

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Leaching Requirement and Crop Yields

After the first planting, the high frequency water application led to weediness, soil compaction and relatively low alfalfa yields. After replanting, better crop yields were obtained. The annual alfalfa yield was around 22 Mg/ha, with no significant difference among treatments. Neither was there a documentable difference between the farmer-irrigated flood check and the three sets of treatment plots.

Based on these results, it is concluded that the leaching requirement for alfalfa irrigated with Colorado River water is less than 5%.

Salinity Status of Soil

Detailed soil samples were taken at the beginning of the experiment, but not at the end--as explained earlier. These samples indicated that the field had been well leached, with $L > 0.20$; there was gypsum present in the soil. After the new regimes had been established, the salinity profiles in the flood check showed that, because of the irrigation frequency, the salinity close to the surface was substantially lower than that in the sprinkler-irrigated plots. The time trends in salinity as measured by sensors followed courses that were consistent with expectations.

Salt Load Reduction

Contrary to the citrus situation, one cannot use the experimental data from the alfalfa experiment directly to illustrate the potential for salt load reduction. One can, however, make the following observation. According to estimates presented at the Advisory Committee Meeting, Wellton-Mohawk Irrigation Efficiency, November 27, 1979, at Phoenix, the average on-farm irrigated efficiency for alfalfa in the District was 74%. Also, recall that ET was found to be 1930 mm, and the irrigation water contained 944 g m^{-3}.

Thus, following the same reasoning as for the citrus, increasing irrigation efficiency to 90%, achievable if $L_R < 0.05$, should change the volume of water delivered per ha by

$$\begin{aligned}\Delta V &= (1.93/0.74 - 1.93/0.90) \times 10^4 \text{ m}^3 \\ &= 4{,}700 \text{ m}^3\end{aligned}$$

and the annual salt load in the drainage water at equilibrium by

$$\begin{aligned}\Delta S &= 0.944 \ \ \Delta V \text{ kg ha}^{-1} \\ &= 4.4 \text{ Mg ha}^{-1}\end{aligned}$$

Adjusting for precipitation (11%) and considering 8,000 ha of alfalfa, the annual reduction in the salt load would be

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$$\Delta S = (4.4)\ (1.11)\ (8{,}000) = 39{,}000\ \text{Mg}.$$

Reductions in Diversions

The salt load reduction mentioned above, as well as in the discussion of the citrus experiment, is achieved by a reduction in the amount of water applied to the land and, therefore, a reduction in diversions from the Colorado River to the District. In fact, in the particular circumstances encountered in this District, the primary operating objective is to reduce to a minimum the volume of water that is needed to discharge the unwanted salt out of the system.

Increasing irrigation efficiency decreases diversions, thus retaining a higher flow in the river for downstream use and reducing the drainage volume that, because of its elevated salt content, is currently discharged to the ocean. Similarly, desalting part of the drainage flow permits returning some water to the river, requiring disposal of the brine stream out of the desalter.

The results obtained in this research enable one to estimate the reduction in drainage water per unit of land that can be expected from irrigation management changes for two important crops. They, thus, decrease the uncertainty of projections of District-wide "savings", were a water management improvement program implemented. Such projections have no place in this report; yet this aspect of the study constitutes a significant finding of substantial importance.

It should be stressed that the consequences of changes in water management, in terms of salt and water balances and in terms of benefits and costs, vary greatly from situation to situation. The data presented here can indeed be extrapolated to other sites; they can also be misapplied elsewhere.

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TABLE A-1. DESCRIPTION OF SOIL AT THE CITRUS EXPERIMENTAL SITE PROVIDED BY THE SOIL CONSERVATION SERVICE

Date: September 27, 1973. Area: Yuma County, Arizona; Lower Gila River Area - 649.
Description by: R.L.A.

Classification: Typic Haplargid, coarse-loamy, mixed, hyperthermic.

Location: Between 21st & 22nd tree west of road & between 19th and 20th tree north of road in East Block No. 220D16, Sec. 20, R. 16 W., T. 8 S.

Vegetation: Valencia oranges. Climate: Arid. Parent Material: Old alluvium. Physiography: Mesa. Relief: A-nearly level. Elevation: 325 feet. Slope: Less than 1%. Aspect: North. Erosion: None to slight. Permeability: Moderate. Drainage: Well. Ground Water: Deep. Moisture: Moist to depth described. Root distribution: Normal.

Additional Notes: Coarse gravel found in a sand matrix from 144 to 206 in. (Dateland fine sandy loam.)

HORIZON	DESCRIPTION
Ap	0-6 inches (0-15 cm), brown (10YR 5/3) fine sandy loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, nonplastic; many fine and very fine roots, many fine and very fine tubular pores; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
B2t	6-17 inches (15-43 cm), light yellowish brown (10YR 6/4) fine sandy loam, dark yellowish brown (10YR 4/4) moist; massive structure; soft to slightly hard, very friable, sticky, slightly plastic; common fine and very fine and very few medium roots, common fine and very fine tubular pores; few thin clay bridges; strongly effervescent; moderately alkaline (pH 8.2), clear smooth boundary.
B3t	17-27 inches (43-69 cm), light yellowish brown (10YR 6/4) fine sandy loam, dark yellowish brown (10YR 4/4) moist; massive structure; soft, very friable, sticky, slightly plastic; very few medium and common fine and very fine roots, many fine and very fine tubular pores; few thin clay bridges; strongly effervescent, fine, irregularly shaped, pinkish white soft masses of lime (2% by volume); moderately alkaline (pH 8.2), clear smooth boundary.

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HORIZON	DESCRIPTION
Clca	27-54 inches (69-137 cm), pale brown (10YR 6/3) loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, slightly plastic; very few medium and coarse and common fine and very fine roots, common fine and very fine tubular pores; violently effervescent, fine and medium, irregularly shaped, pinkish white soft masses of lime (25% by volume); moderately alkaline (pH 8.2), clear wavy boundary.
C2	54-57 inches (137-145 cm), pale brown (10YR 6/3) fine sandy loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, nonplastic; common very fine and few fine roots, many fine and very fine tubular pores; strongly effervescent, fine irregularly shaped concretions of lime (<1% by volume); moderately alkaline (pH 8.2), clear wavy boundary.
IIC3	57-74 (145-188 cm), pale brown (10YR 6/3) sand, brown (10YR 5/3) moist; massive structure; loose, very friable, nonsticky, nonplastic; very few fine roots, many interstitial pores; noneffervescent, moderately alkaline (pH 8.2); clear wavy boundary.
IIC4	74-84 inches (188-213 cm) pale brown (10YR 6/3) sand, dark brown (10YR 4/3) moist, massive structure; loose, very friable, nonsticky, nonplastic; many interstitial pores; 15% gravel (by volume), noneffervescent, moderately alkaline (pH 8.2), clear wavy boundary.
IIC5	84-94 inches (214-239 cm), pale brown (10YR 6/3) sand, dark grayish brown (10YR 4/2) moist; massive structure; loose, very friable, nonsticky, nonplastic, many interstitial pores; noneffervescent, moderately alkaline (pH 8.2).

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TABLE A-2. RAINFALL, TOTALLED AS mm PER MONTH, AT THE VALENCIA ORANGE EXPERIMENT

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mm
1974	14	0	5	0	0	0	18	4	48	7	2	7	105
1975	4	1	7	17	0	0	4	1	32	0	6	13	85
1976	2	18	7	13	1	0	30	0	14	25	7	1	118
1977	20	1	2	0	2	0	2	76	22	8	0	14	147
1978	37	7	14	5	0	0	5	2	2	19	22	13	126
Avg.	15	5	7	7	1	0	12	17	23	12	7	10	116

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TABLE A-3. DAILY RATE OF EVAPORATION (mm), AVERAGED ON A MONTHLY BASIS, FOR A CLASS A PAN LOCATED WITHIN THE VALENCIA ORANGE GROVE IN THE PLACE ON A TREE ABOUT 0.5 km NORTH OF THE EXPERIMENT

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mm
1974	1.2	3.2	4.3	5.9	7.6	8.7	8.2	8.0	6.5	4.2	1.9	0.8	1840
1975	0.9	2.6	3.9	5.1	7.1	8.3	8.1	7.9	6.1	4.2	1.8	0.6	1730
1976	0.9	2.2	4.2	5.4	7.0	7.6	7.2	7.6	4.9	3.7	1.2	0.6	1600
1977	0.6	2.0	-*	-	-	7.7	7.7	7.0	5.6	3.8	1.4	0.6	1610**
1978	0.5	1.8	3.6	5.0	6.5	8.1	7.6	7.2	5.9	3.4	1.0	0.5	1560
Avg.	0.8	2.4	4.0	5.4	7.1	8.1	7.8	7.5	5.8	3.9	1.5	0.6	1670

* Valves excessively high because of honey bees drinking from pan.

** Average monthly values used for March, April, and May.

TABLE A-4. DAILY RATE OF EVAPORATION (mm), AVERAGED ON A MONTHLY BASIS, FOR A CLASS A PAN AT THE UNIVERSITY OF ARIZONA MESA EXPERIMENT STATION, YUMA, ARIZONA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mm
1974	2.9	4.7	4.4	9.0	10.6	10.0	10.6	10.3	8.9	5.6	3.6	2.9	2540
1975	3.6	3.9	5.2	7.2	9.4	10.4	11.4	10.7	8.2	5.7	4.4	2.6	2520
1976	3.1	3.4	6.0	7.4	8.8	12.8	10.8	10.5	6.8	5.6	4.2	3.5	2530
1977	2.6	4.8	6.0	7.5	9.1	11.5	11.6	9.5	7.6	5.4	4.6	2.6	2520
1978	2.0	3.4	5.1	7.3	9.7	12.1	11.8	10.6	8.9	5.4	3.3	2.6	2510
Avg.	2.8	4.0	5.3	7.7	9.5	11.4	11.2	10.3	8.1	5.5	4.0	2.8	2520

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TABLE A-5. METEOROLOGICAL DATA AND COEFFICIENTS REQUIRED FOR PREDICTING EVAPOTRANSPIRATION OF MATURE VALENCIA ORANGE TREES IN AN ARID CLIMATE

Month	Daily Pan* Evaporation	Crop** Coeff.	Daily Solar Radiation	Weighing Factor	Mean Temp.	Percent Daytime Hours	Day-Night Weather Condition	Daily Net Radiation	Wind Function	Vapor Pressure Difference
	E_p mm	k_c	R_s† mm	W	T °C	p	k_w	R_m† mm	f(u)	$e_o - e$ mb
Jan	2.8	0.75	4.6	0.56	10.4	0.24	0.79	2.1	0.53	4.9
Feb	4.0	0.75	6.2	0.59	12.9	0.25	0.81	3.5	0.64	6.7
Mar	5.3	0.80	7.9	0.63	15.5	0.27	0.84	5.4	0.69	7.5
Apr	7.7	0.80	10.5	0.66	18.2	0.29	0.88	8.0	0.72	7.9
May	9.5	0.80	11.4	0.71	23.1	0.31	0.89	8.9	0.74	12.3
Jun	11.4	0.85	11.8	0.77	28.4	0.32	0.94	9.6	0.74	17.1
Jul	11.2	0.85	10.5	0.80	31.5	0.31	0.93	8.9	0.79	17.7
Aug	10.3	0.85	10.3	0.79	30.9	0.30	0.91	8.5	0.74	17.2
Sep	8.1	0.85	8.3	0.77	27.9	0.28	0.88	6.5	0.67	13.9
Oct	5.5	0.85	6.9	0.71	22.1	0.26	0.85	4.7	0.57	10.5
Nov	4.0	0.80	5.4	0.62	14.7	0.24	0.80	2.8	0.53	7.2
Dec	2.8	0.80	4.2	0.56	10.3	0.23	0.77	1.7	0.49	5.6

* Mean values of data from the Yuma Mesa Experiment Station of the University of Arizona from 1974 through 1978. (R. L. Roth, personal communication, 1979).

** Taken from Doorenbos and Pruitt (1975).

† Expressed as equivalent depth of evaporation of water.

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TABLE A-6. AVERAGE ANNUAL VALENCIA ORANGE YIELD PER TREE (kg) FOR THE LEACHING FRACTION EXPERIMENT IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Year	Treatment Replication									Treatment Average
	1	2	3	4	5	6	7	8	9	
					5% Leaching					
1974	12	124	132	138	105	110	108	105	98	116
1975	124	135	130	154	149	149	152	149	143	143
1976	63	45	70	68	81	86	70	97	83	74
1977	161	180	174	175	174	170	154	156	158	167
1978	133	129	135	120	143	174	133	176	147	143
1979	77	74	88	81	89	83	102	103	80	86
Mean	114	114	122	123	124	129	120	131	118	122
					10% Leaching					
1974	132	139	137	122	129	125	124	117	108	126
1975	106	131	160	150	165	149	165	159	141	147
1976	48	62	61	57	69	79	68	81	107	70
1977	169	187	186	175	193	164	184	174	160	177
1978	118	110	113	150	136	147	149	162	160	138
1979	66	99	95	111	97	125	141	114	108	106
Mean	107	121	125	128	132	132	138	134	131	128
					25% Leaching					
1974	143	138	123	117	106	112	122	119	117	122
1975	128	170	155	132	134	152	166	138	147	147
1976	75	58	60	59	68	62	88	80	90	71
1977	180	176	175	170	162	176	188	172	160	173
1978	128	136	146	132	146	144	164	153	133	142
1979	117	113	113	105	124	119	137	136	98	118
Mean	128	132	129	119	123	128	144	133	124	129

	Bubbler Border		Drip Border		Flood Check			Fertilizer Check		
	West Row	East Row	West Row	East Row	West Row	Center Row	East Row	West Row	Center Row	East Row
1974	127	118	108	116	---[a]	---	---	---	---	---
1975	140	142	160	170	116	131	115	171	186	177
1976	76	76	84	91	88	103	103	100	112	104
1977	171	178	166	172	130	143	119	164	179	179
1978	134	144	154	164	118	130	131	207	191	192
1979	106	94	76	59	129	135	152	107	151	144
Mean	126	125	125	129	116	128	124	150	164	159

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[a] Trees were not individually harvested in 1974.

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TABLE A-7. AVERAGE NUMBER OF VALENCIA ORANGE FRUIT HARVESTED PER TREE BY REPLICATION FOR THE LEACHING FRACTION TREATMENTS AND BY ROW FOR THE BORDER- AND CHECK-PLOTS IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Year	Treatment Replication									Treatment Average
	1	2	3	4	5	6	7	8	9	
					5% Leaching					
1974	607	592	664	583	422	396	513	481	424	520
1975	685	744	719	846	820	824	836	821	788	787
1976	293	196	310	277	379	340	343	441	388	330
1977	859	921	907	928	918	860	812	779	785	863
1978	697	667	796	641	641	825	702	919	822	746
1979	576	480	585	571	486	434	616	564	498	534
Mean	620	600	664	641	611	613	637	668	618	630
					10% Leaching					
1974	661	637	622	505	538	569	558	506	429	558
1975	569	706	859	805	888	803	889	856	813	799
1976	225	252	248	229	275	357	272	367	477	300
1977	870	986	959	950	1017	801	906	893	807	910
1978	571	499	611	651	688	782	697	828	830	684
1979	470	639	597	676	533	718	856	597	604	632
Mean	561	620	649	636	656	672	696	674	660	647
					20% Leaching					
1974	693	604	583	567	528	487	513	562	493	559
1975	682	905	825	703	711	809	882	731	781	781
1976	314	230	275	239	333	267	359	358	404	309
1977	914	918	915	843	815	915	979	852	806	884
1978	565	641	658	649	711	701	742	701	626	666
1979	800	769	695	595	737	700	812	797	556	718
Mean	661	678	658	599	639	646	714	667	611	653

	Bubbler Border		Drip Border		Flood Check			Fertilizer Check		
	West Row	East Row	West Row	East Row	West Row	Center Row	East Row	West Row	Center Row	East Row
1974	569	530	461	494	---	---	---	---	---	---
1975	701	711	845	898	499	562	493	901	982	934
1976	310	321	335	364	386	457	436	393	426	401
1977	819	864	846	856	696	777	644	844	906	946
1978	687	707	810	884	537	562	592	989	925	963
1979	668	599	508	384	786	806	930	580	840	756
Mean	626	622	634	647	581	633	619	741	816	800

TABLE A-8. PERIODIC MEASUREMENTS OF VALENCIA ORANGE TREE TRUNK CIRCUMFERENCE (mm) AVERAGED BY REPLICATION FOR THE LEACHING FRACTION TREATMENTS AND BY ROW FOR THE BORDER- AND CHECK-PLOTS IN SOUTHWEST ARIZONA FROM 1974 TO 1979

Month/Year	Treatment Replication									Treatment Average
	1	2	3	4	5	6	7	8	9	
					5% Leaching					
Sept 1973	550	575	565	565	590	585	590	580	565	575
July 1974	545	580	580	585	610	590	585	590	580	580
Aug 1975	575	615	610	615	635	620	620	625	610	615
July 1976	630	650	660	650	665	650	645	655	640	650
July 1977	660	685	690	680	685	680	695	695	655	680
July 1978	710	700	725	690	725	725	710	705	700	710
					10% Leaching					
Sept 1973	555	565	575	575	560	575	585	590	555	570
July 1974	585	580	575	600	565	600	600	605	570	585
Aug 1975	620	605	615	635	600	630	630	635	605	620
July 1976	650	655	650	665	635	670	670	670	635	655
July 1977	655	660	685	690	670	695	655	680	675	675
July 1978	690	725	695	720	690	695	720	710	715	705
					20% Leaching					
Sept 1973	570	565	580	540	560	575	575	555	555	565
July 1974	585	580	590	550	575	580	600	575	585	580
Aug 1975	620	615	630	590	610	615	640	605	615	615
July 1976	655	660	665	630	645	660	675	640	655	655
July 1977	690	685	700	660	660	665	710	690	690	685
July 1978	700	725	730	730	715	705	730	730	665	715

	Bubbler Border		Drip Border		Flood Check			Fertilizer Check		
	West Row	East Row	West Row	East Row	West Row	Center Row	East Row	West Row	Center Row	East Row
Sept 1973	540	560	565	590	---	---	---	550	---	545
July 1974	575	575	595	605	535	---	515	---	---	---
Aug 1975	615	615	600	630	---	575	555	605	605	595
July 1976	640	640	660	675	---	600	580	620	630	630
July 1977	670	685	705	680	605	625	610	645	660	660
July 1978	695	695	705	730	615	650	630	670	675	680

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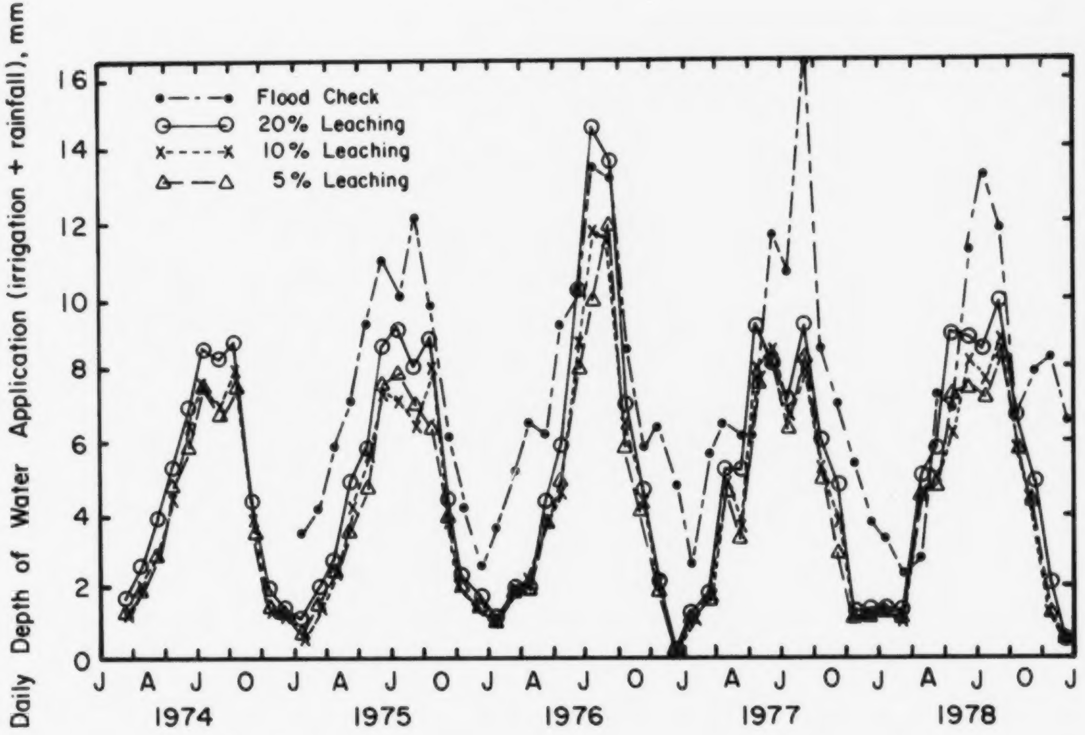

Fig. A-1. The daily application of water, averaged by month, for the 5, 10, and 20% leaching treatments and the flood check for the citrus experiment from 1974 through 1978.

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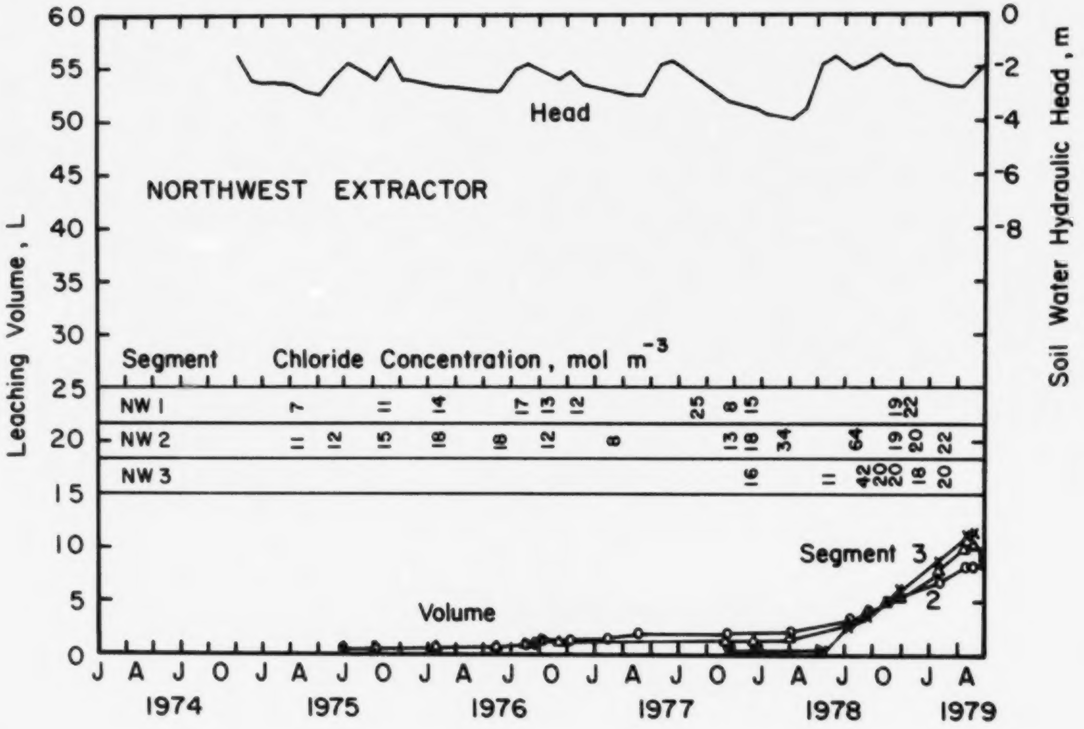

Fig. A-2a. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot H6 (refer to Fig. 2 for exact location).

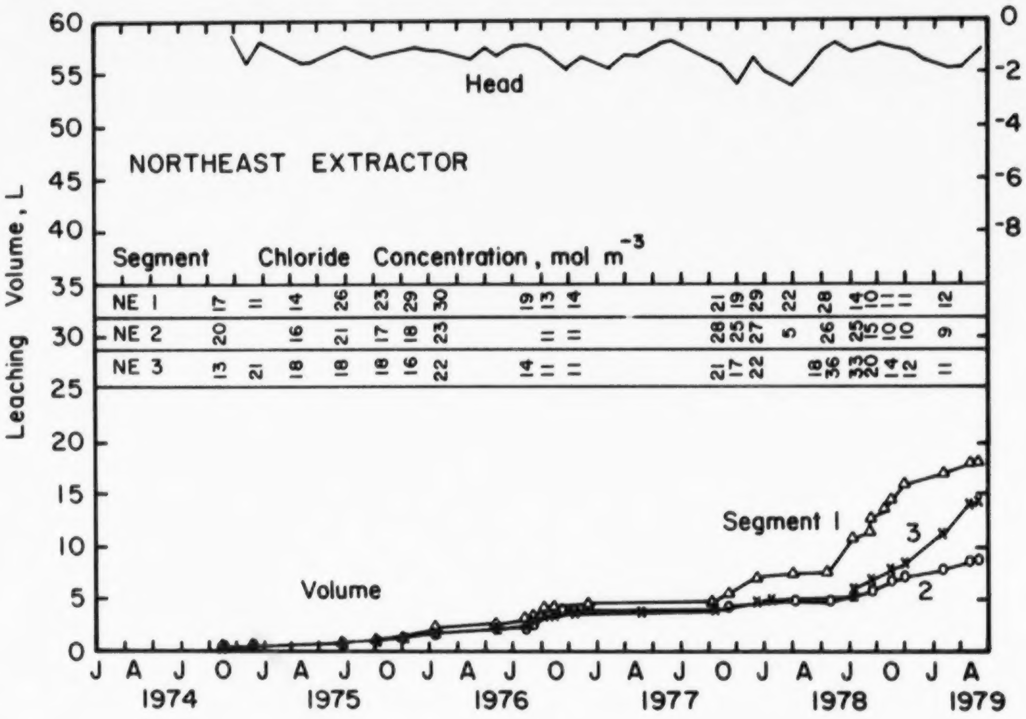

Fig. A-2b. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot H6 (refer to Fig. 2 for exact location).

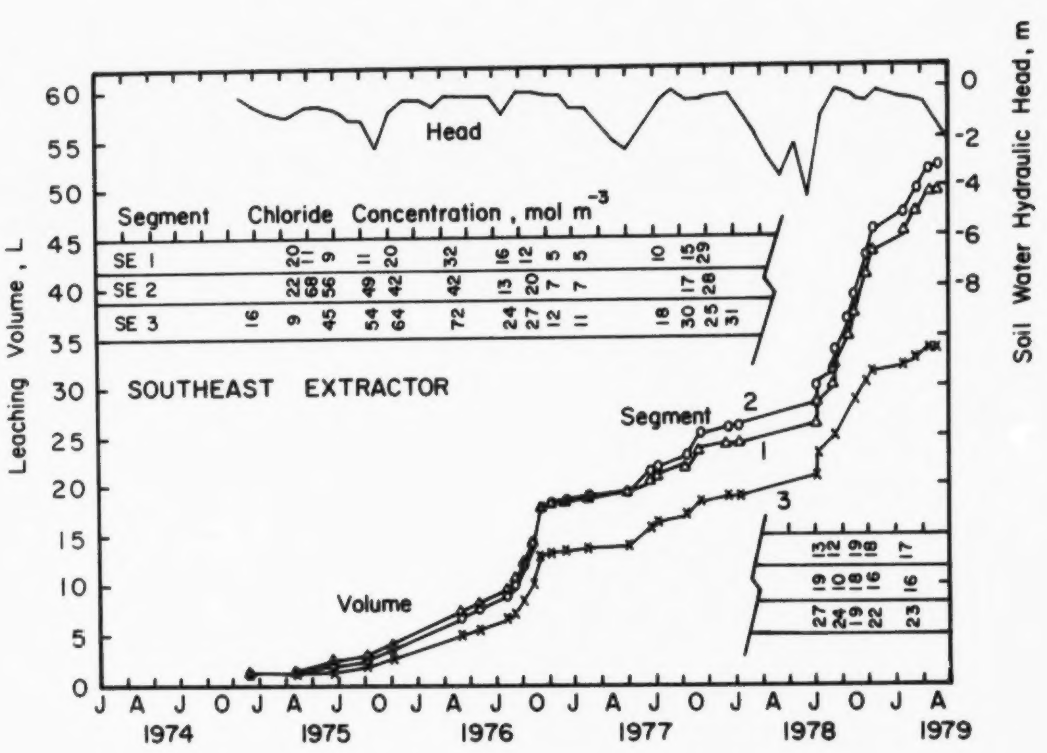

Fig. A-2c. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot H6 (refer to Fig. 2 for exact location).

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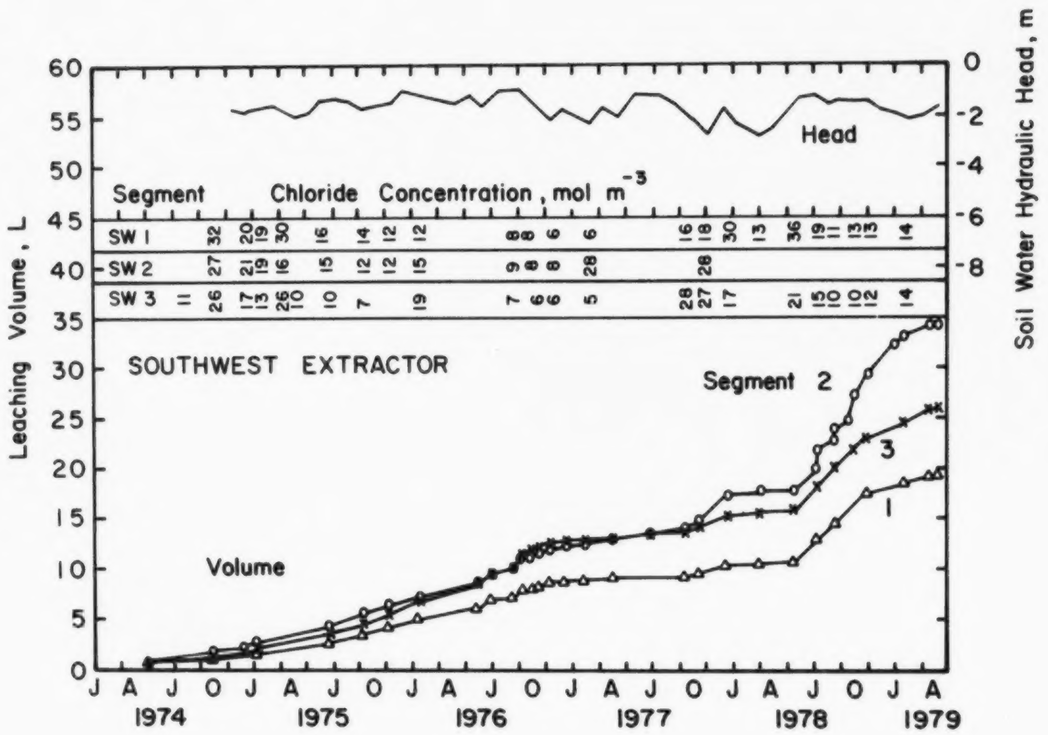

Fig. A-2d. Volume of leachate, average sol water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot H6 (refer to Fig. 2 for exact location).

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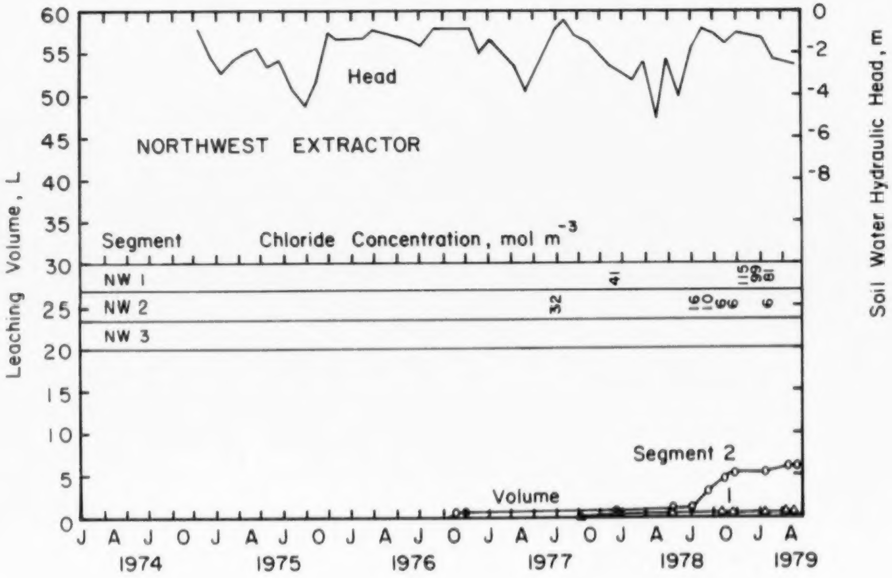

Fig. A-3a. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot L7 (refer to Fig. 2 for exact location).

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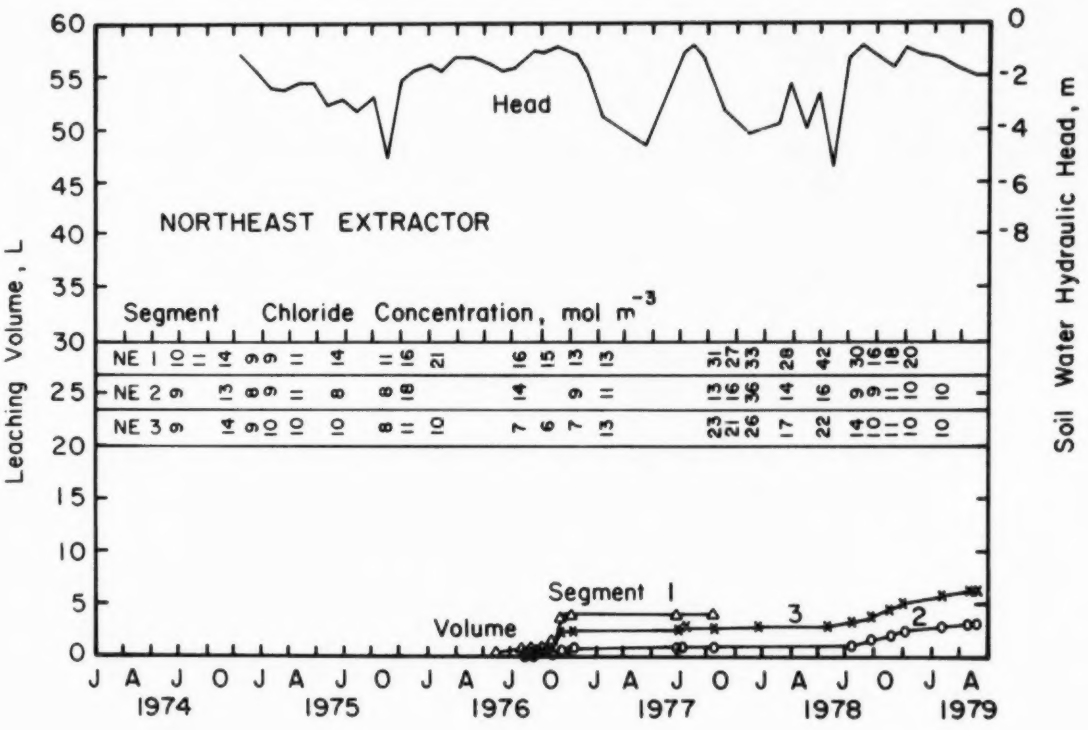

Fig. A-3b. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot L7 (refer to Fig. 2 for exact location).

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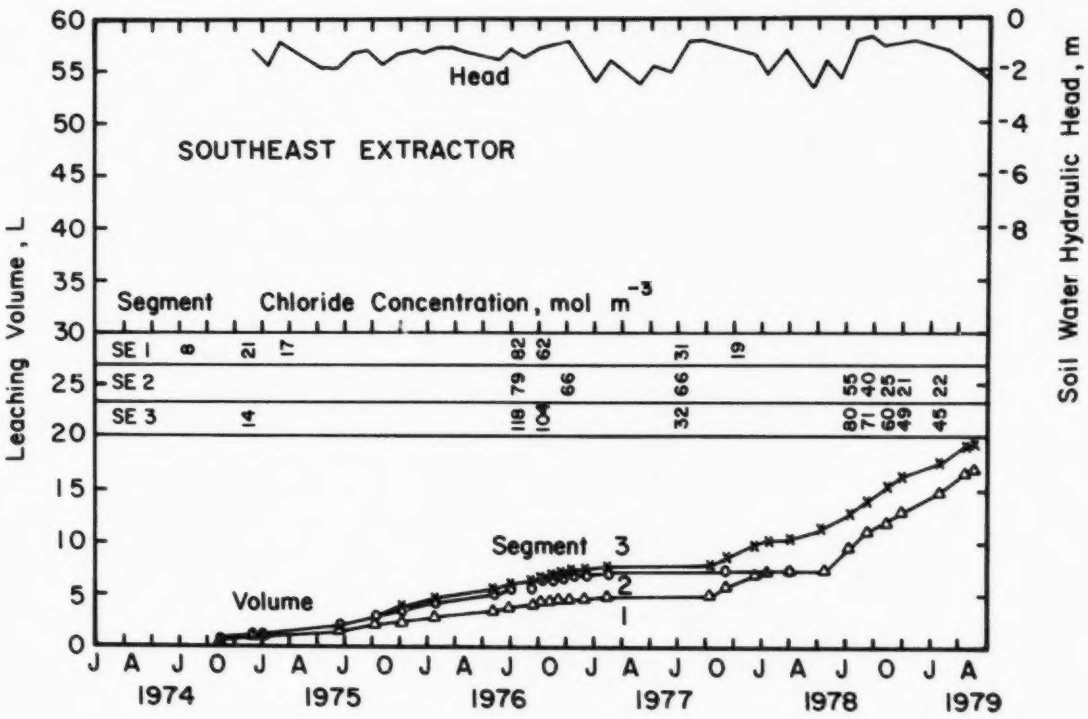

Fig. A-3c. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the three individual segments of the extractor. Results are for the northwest extractor in plot L7 (refer to Fig. 2 for exact location).

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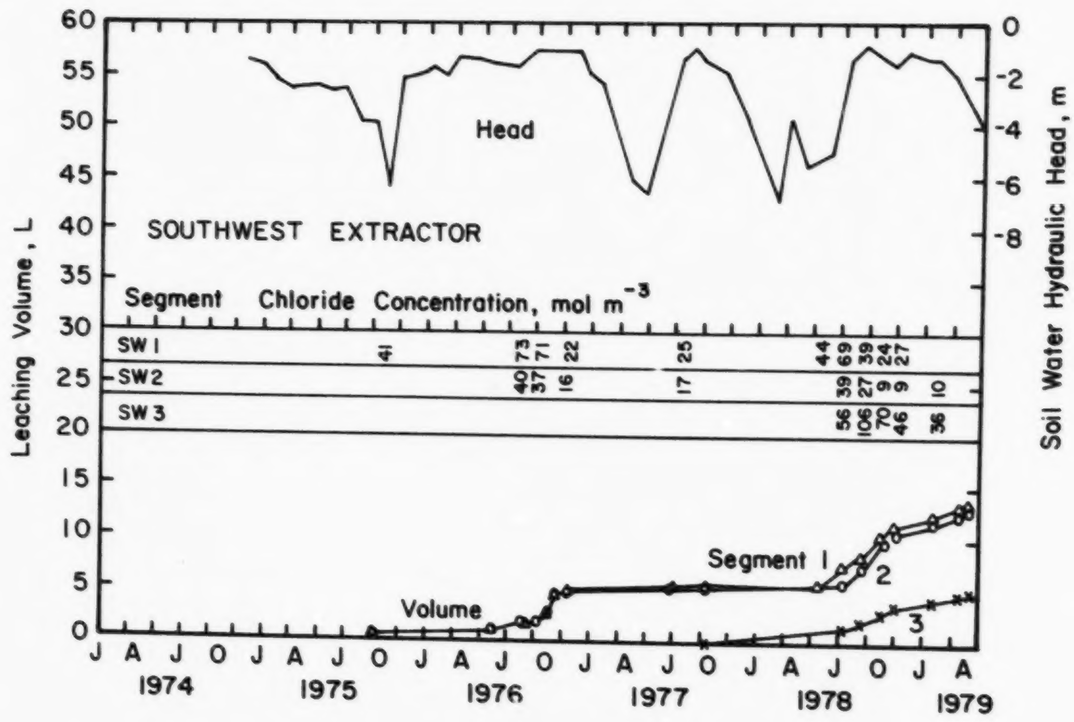

Fig. A-3d. Volume of leachate, average soil water hydraulic head, and chloride concentration of the leachate water for each of the the three individual segments of the extractor. Results are for the northwest extractor in plot L7 (refer to Fig. 2 for exact location).

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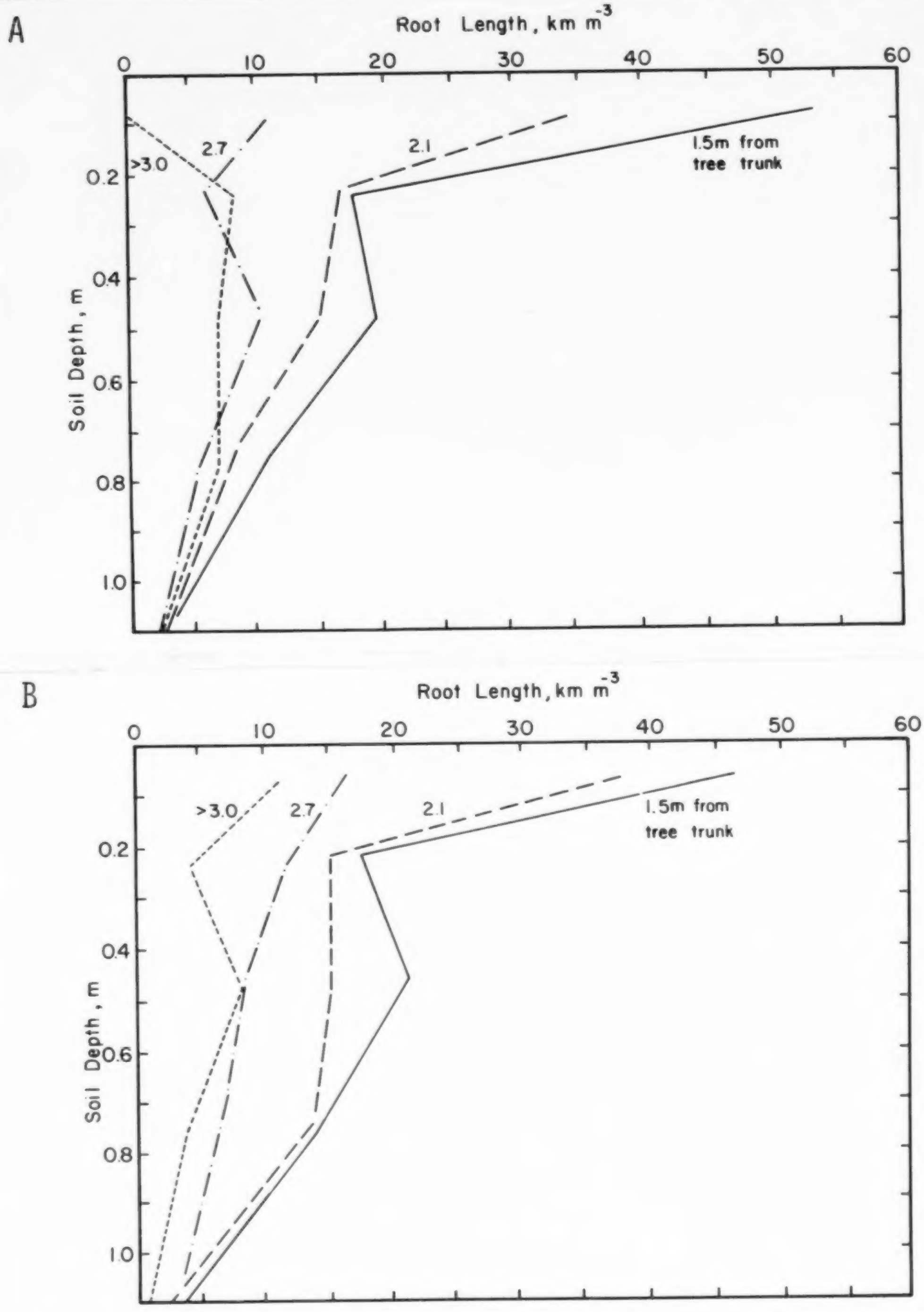

Fig. A-4. Root lengths for the 5 (A) and 20% (B) leaching treatments as a function of distance from the trunk and soil depth.

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

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TABLE B-1. DESCRIPTION OF SOIL AT THE ALFALFA EXPERIMENTAL SITE PROVIDED BY THE SOIL CONSERVATION SERVICE

Date: September 10, 1974. Area: Yuma County, Arizona.
Description by: E. Chamberlin and J. White.
Classification: Typic Torrifluvent, coarse-silty, mixed, calcareaous, hyperthermic.
Location: 800'E, 900'S. of NW corner section 12, T. 8.S., R.16.W. of G. & S.R. B. L. & M.
Vegetation: Fallow. Climate: 2-4 inches precipitation, mean annual air temp. 70-75°F. Parent Material: Gila River alluvium. Topography: Level. Elevation: 288'. Drainage: Well-drained.
Additional Notes: Indio very fine sandy loam (color for dry soil unless otherwise noted)

HORIZON	DESCRIPTION
Ap	0-13 inches (0-33 cm); light brown (7.5YR 6/4) very fine sandy loam, brown (7.5YR 4/4) moist; weak granular structure; soft, very friable, nonsticky, nonplastic; common medium and fine roots; common medium tubular and many fine interstitial roots; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
C1	13-21 inches (33-53 cm) light brown (7.5YR 6/4) silt loam, brown (7.5YR 4/4) moist; weak very fine platy structure; slightly hard, very friable, slightly sticky, slightly plastic, few medium and many fine roots; common tubular and many very fine interstitial pores; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
C2	21-33 inches (53-84 cm); light brown (7.5YR 6/4) silt loam, brown (7.5YR 4/4) moist; massive; slightly hard, very friable, slightly sticky, slightly plastic; few medium and fine roots; few tubular and many very fine interstitial pores; strongly effervescent; moderately alkaline (pH 8.5); clear smooth boundary.
C3	33-45 inches (84-114 cm); light brown (7.5YR 6/4) silty clay loam; brown (7.5YR 4/4) moist; massive; hard, friable, sticky slightly plastic; few tubular and many very fine interstitial pores; strongly effervescent; moderately alkaline (pH 8.4); clear smooth boundary.
C4	45-72 inches (114-182 cm); light brown (7.5YR 6/4) silty clay loam, brown (7.5YR 4/4) moist; massive; slightly hard, friable, sticky, plastic, few tubular and many very fine interstitial pores; strongly effervescent; strongly alkaline (pH 8.8).

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TABLE B-2. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES IN THE 0- TO 0.3-m DEPTH INTERVAL AT THE BEGINNING OF THE ALFALFA EXPERIMENT

Plot	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
	dS m^{-1}	$(mol\ m^{-3})^{1/2}$	kg kg^{-1}	mol m^{-3}							
I5	2.3 (0.6)*	5.0 (0.5)	0.43 (0.01)	4.5 (1.9)	2.6 (0.9)	12.7 (2.7)	0.4 (0.1)	3.1 (0.8)	8.4 (3.6)	5.8 (0.9)	1.1 (0.6)
II5	2.6 (0.4)	6.0 (1.1)	0.42 (0.02)	4.5 (1.2)	2.2 (0.5)	15.5 (3.8)	0.33 (0.2)	2.9 (0.8)	9.0 (2.3)	6.2 (2.2)	2.0 (0.8)
I10	2.3 (0.5)	5.3 (0.5)	0.41 (0.05)	4.2 (1.4)	2.0 (0.7)	13.0 (2.4)	0.35 (0.1)	2.9 (0.5	7.8 (2.9)	5.7 (1.9)	1.6 (0.8)
II10	2.6 (14)	5.5 (0.8)	0.39 (0.05)	5.1 (4.5)	2.6 (2.4)	14.4 (6.9)	0.28 (0.1)	2.5 (0.4)	9.2 (7.2)	7.8 (6.9)	1.5 (0.8)
II20	2.5 (1.1)	6.2 (1.5)	0.43 (0.02)	4.4 (2.4)	2.5 (1.5)	16.5 (8.2)	0.40 (0.21)	2.8 (0.4)	9.0 (5.5)	7.2 (3.9)	2.1 (1.0)
III20	2.0 (0.4)	5.4 (0.3)	0.41 (0.01)	3.4 (1.1)	3.0 (0.4)	11.9 (2.2)	0.30 (0.09)	2.8 (0.8)	6.2 (2.3)	4.8 (0.6)	1.8 (0.8)
FLOOD	2.2 (0.6)	5.1 (0.8)	0.40 (0.04)	3.8 (2.1)	2.1 (1.1)	12.2 (3.3)	0.25 (0.1)	1.6 (0.3)	7.7 (4.4)	5.2 (1.6)	2.0 (0.8)

* Standard deviation assuming normal distribution.

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TABLE B-3. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES IN THE 0.3- TO 0.6-m DEPTH INTERVAL AT THE BEGINNING OF THE ALFALFA EXPERIMENT

Plot	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
	dS m^{-1}	(mol $m^{-3})^{1/2}$	kg kg^{-1}	mol m^{-3}							
I5	3.3 (0.4)*	5.3 (1.0)	0.41 (0.03)	7.1 (1.4)	3.4 (0.6)	17.2 (3.7)	0.4 (0.1)	2.0 (0.7)	11.4 (1.8)	13.2 (2.4)	0.6 (0.2)
II5	4.5 (1.5)	6.6 (1.8)	0.42 (0.03)	9.2 (2.0)	5.4 (2.5)	25.8 (11.4)	0.4 (0.2)	1.8 (0.6)	18.5 (8.4)	16.6 (4.1)	0.7 (0.2)
I10	3.1 (0.6)	5.2 (0.6)	0.45 (0.07)	6.8 (1.6)	3.2 (1.1)	16.3 (2.2)	0.4 (0.1)	2.1 (0.8)	11.2 (2.8)	11.0 (1.5)	1.3 (0.9)
II10	2.7 (0.6)	5.4 (0.8)	0.41 (0.04)	5.2 (3.2)	2.6 (1.0)	15.1 (3.8)	0.4 (0.2)	1.8 (0.5)	9.3 (3.0)	9.4 (2.4)	1.6 (1.1)
II20	3.8 (1.1)	5.8 (1.0)	0.42 (0.05)	8.2 (3.0)	4.3 (2.3)	20.7 (7.0)	0.5 (0.3)	1.9 (0.6)	15.0 (6.5)	13.9 (5.6)	1.2 (0.9)
III20	3.2 (0.5)	5.3 (0.8)	0.43 (0.04)	6.3 (2.6)	3.5 (0.9)	16.9 (3.8)	0.3 (0.2)	1.7 (0.5)	11.9 (2.7)	11.5 (2.1)	0.6 (0.2)
FLOOD	2.4 (0.6)	5.9 (0.9)	0.42 (0.08)	4.5 (1.8)	2.5 (1.2)	14.7 (3.7)	0.2 (0.1)	1.2 (0.3)	9.2 (3.3)	7.4 (2.9)	1.0 (0.4)

* Standard deviation assuming normal distribution.

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TABLE B-4. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES IN THE 0.6- TO 0.9-m DEPTH INTERVAL AT THE BEGINNING OF THE ALFALFA EXPERIMENT

Plot	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
	dS m^{-1}	$(mol\ m^{-3})^{1/2}$	kg kg^{-1}	mol m^{-3}							
I5	2.5 (0.2)*	5.9 (1.2)	0.48 (0.05)	4.4 (0.8)	2.2 (0.4)	15.0 (2.4)	0.3 (0.1)	1.9 (0.2)	9.1 (1.2)	7.9 (0.9)	0.4 (0.3)
II5	4.3 (1.6)	6.0 (2.0)	0.49 (0.07)	6.3 (1.7)	3.8 (0.8)	29.7 (19.9)	0.5 (0.2)	2.2 (1.1)	16.5 (5.5)	15.9 (7.5)	0.5 (0.2)
I10	2.6 (0.6)	5.9 (0.7)	0.49 (0.08)	4.3 (1.4)	2.3 (0.8)	15.3 (3.4)	0.3 (0.2)	1.9 (0.5)	9.2 (2.5)	8.2 (2.5)	0.6 (0.1)
II10	3.0 (0.8)	5.6 (0.8)	0.49 (0.02)	6.2 (3.7)	3.5 (2.5)	16.6 (3.5)	0.3 (0.2)	1.8 (0.3)	9.3 (7.7)	8.4 (2.0)	1.0 (0.5)
II20	4.0 (2.2)	5.0 (2.4)	0.48 (0.04)	7.3 (4.6)	4.8 (3.1)	24.7 (15.1)	0.6 (0.6)	2.0 (0.6)	15.3 (8.4)	16.6 (13.8)	0.8 (0.4)
III20	3.0 (0.6)	5.7 (0.5)	0.45 (0.04)	5.6 (1.3)	3.3 (1.2)	17.1 (3.5)	0.2 (0.1)	1.7 (0.4)	11.6 (2.7)	10.1 (2.7)	0.5 (0.3)
FLOOD	2.6 (0.8)	5.8 (0.9)	0.49 (0.06)	4.7 (3.2)	2.9 (1.8)	14.9 (3.0)	0.2 (0.2)	1.3 (0.3)	10.6 (5.7)	7.1 (3.3)	1.0 (0.3)

* Standard deviation assuming normal distribution.

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TABLE B-5. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES IN THE 0.9- TO 1.2-m. DEPTH INTERVAL AT THE BEGINNING OF THE ALFALFA EXPERIMENT

Plot	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
	dS m^{-1}	(mol $m^{-3})^{1/2}$	kg kg^{-1}	mol m^{-3}							
I5	2.6 (0.8)*	5.4 (1.2)	0.49 (0.05)	5.3 (4.1)	2.2 (0.5)	14.2 (3.1)	0.3 (0.2)	1.8 (0.3)	10.0 (5.1)	7.4 (1.2)	0.3 (0.2)
II5	3.9 (0.9)	4.1 (2.4)	0.54 (0.04)	5.3 (3.2)	2.9 (1.5)	30.0 (16.6)	0.3 (0.2)	2.4 (1.9)	16.1 (4.2)	12.4 (2.0)	0.4 (0.2)
I10	2.8 (1.0)	5.4 (0.7)	0.54 (0.09)	5.6 (3.8)	3.3 (1.9)	15.8 (5.3)	0.3 (0.2)	1.9 (0.3)	12.1 (8.0)	7.9 (2.4)	0.4 (0.2)
III10	2.9 (1.1)	5.7 (0.8)	0.58 (0.09)	5.3 (4.0)	3.7 (2.9)	16.0 (4.9)	0.4 (0.2)	1.8 (0.3)	11.8 (8.2)	8.6 (2.5)	0.6 (0.2)
II20	4.4 (2.3)	3.6 (2.3)	0.56 (0.13)	8.1 (4.1)	4.7 (2.7)	29.2 (19.3)	0.8 (0.9)	1.6 (0.5)	20.6 (14.3)	12.7 (7.4)	0.5 (0.2)
III20	3.5 (1.3)	5.6 (0.8)	0.50 (0.05)	7.6 (4.7)	4.5 (2.3)	19.1 (7.1)	0.3 (0.1)	1.5 (0.4)	15.8 (9.0)	10.6 (3.9)	0.4 (0.2)
FLOOD	2.9 (0.8)	5.8 (1.1)	0.53 (0.04)	5.4 (3.6)	3.6 (1.7)	16.5 (3.3)	0.2 (0.2)	1.3 (0.4)	12.5 (6.5)	7.8 (2.9)	1.0 (0.6)

* Standard deviation assuming normal distribution.

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TABLE B-6. AVERAGE VALUES FOR SELECTED SOIL CHEMICAL PROPERTIES IN THE 1.2- TO 1.5-m DEPTH INTERVAL IN THE BEGINNING OF THE ALFALFA EXPERIMENT

Plot	σ_e	R_{Na}	W_s	Cations				Anions			
				Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
	dS m^{-1}	(mol $m^{-3})^{1/2}$	kg kg^{-1}	-------------------------mol m^{-3}				-------------------------			
I5	2.7 (0.8)*	4.9 (1.9)	0.54 (0.03)	5.0 (4.7)	2.1 (1.0)	16.6 (5.7)	0.2 (0.1)	1.9 (0.5)	11.0 (5.8)	7.4 (1.5)	0.2 (0.1)
II5	4.5 (3.1)	4.4 (2.1)	0.53 (0.05)	4.8 (3.4)	2.3 (1.3)	22.0 (10.7)	0.4 (0.2)	2.3 (1.4)	10.9 (3.2)	10.3 (1.8)	0.5 (0.5)
I10	2.7 (0.9)	6.1 (1.1)	0.61 (0.06)	4.9 (3.7)	2.5 (0.5)	16.1 (4.8)	0.3 (0.1)	1.8 (0.2)	11.2 (6.6)	7.4 (1.4)	0.3 (0.2)
III10	2.9 (0.9)	5.5 (2.4)	0.56 (0.06)	4.0 (1.5)	3.1 (1.2)	19.7 (9.2)	0.4 (0.2)	1.8 (0.2)	11.6 (5.6)	8.6 (2.6)	0.5 (0.2)
II20	4.8 (1.8)	3.6 (2.2)	0.57 (0.09)	10.5 (4.1)	4.6 (2.2)	33.0 (21.8	0.6 (0.6)	1.5 (0.4)	26.0 (12.6)	9.6 (1.5)	0.4 (0.1)
III20	3.2 (1.3)	5.7 (1.2)	0.57 (0.07)	6.8 (4.7)	3.8 (2.0)	18.1 (7.5)	0.3 (0.1)	1.6 (0.4)	15.0 (10.0)	8.8 (3.2)	0.4 (0.2)
FLOOD	3.2 (1.0)	6.1 (1.4)	0.55 (0.06)	6.4 (4.5)	4.5 (2.5)	18.4 (4.6)	0.3 (0.2)	1.2 (0.4)	15.5 (9.2)	7.5 (2.8)	0.8 (0.4)

* Standard deviation assuming normal distribution.

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TABLE B-7. AVERAGE LEACHATE WATER COMPOSITIONS FROM THE VACUUM EXTRACTORS FOR THE ALFALFA EXPERIMENT BY YEAR FOR THE 5% LEACHING TREATMENT

Year	N*	σ	R_{Na}	pH	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
		dS m^{-1}	$(mol\ m^{-3})^{1/2}$		mol m^{-3}							
Plot I5												
North Extractor												
1976	3	10.0	6.3	7.2	51.0	36.8	41.5	1.4	13.5	48.9	66.7	0.4
1977	4	15.5	7.4	6.8	79.1	51.8	59.5	1.9	9.6	47.6	132.8	2.1
1978	6	15.0	8.5	7.3	66.6	46.3	63.7	1.6	9.0	43.7	126.4	1.0
South Extractor												
1975	3	7.1	6.4	7.1	37.7	23.7	35.8	1.1	11.2	49.2	35.9	1.6
1976	7	9.6	6.8	7.1	47.3	32.7	43.2	1.3	11.8	54.3	57.7	0.6
1977	5	11.4	9.4	7.0	47.0	35.9	60.5	1.6	13.1	66.4	66.8	1.2
1978	5	12.8	11.8	7.3	46.2	37.5	75.6	1.5	12.4	64.8	81.4	0.8
Plot II5												
North Extractor												
1975	5	13.2	18.8	7.4	33.6	39.1	112.8	0.8	19.9	103.3	63.4	0.3
1976	6	15.3	23.5	7.4	30.2	42.8	141.7	0.9	24.2	137.2	57.0	0.6
1977	6	15.3	29.3	7.5	19.9	32.3	150.7	0.9	16.7	135.5	53.5	1.4
1978	6	15.7	32.0	7.8	17.8	28.9	153.3	0.9	16.5	130.7	54.7	0.5
South Extractor												
1975	5	9.9	14.2	7.2	30.9	29.7	77.3	0.7	20.6	82.5	36.3	0.5
1976	8	11.9	14.8	7.3	32.6	36.4	87.2	0.8	20.9	72.7	63.9	0.6
1977	6	10.1	13.8	7.3	27.2	33.0	75.9	0.7	17.0	85.3	34.7	1.0
1978	3	9.9	15.7	7.7	19.9	32.1	79.9	0.7	14.7	90.9	26.4	0.5

* Number of samples analyzed.

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TABLE B-8. AVERAGE LEACHATE WATER COMPOSITIONS FROM THE VACUUM EXTRACTORS FOR THE ALFALFA EXPERIMENT BY YEAR FOR THE 10% LEACHING TREATMENT

Year	n*	σ	R_{Na}	pH	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
		dS m^{-1}	(mol $m^{-3})^{1/2}$		-----------------	-----------------	-----------------	-----------------	mol m^{-3}	-----------------	-----------------	-----------------
					Plot I10							
					North Extractor							
1975	7	9.8	9.4	7.2	46.5	35.3	60.3	0.8	17.5	72.7	50.9	0.5
1976	8	12.4	12.6	7.2	47.0	39.3	83.2	0.9	12.4	88.1	67.7	0.7
1977	6	11.7	15.5	7.4	35.9	29.9	88.4	0.9	6.1	88.7	57.2	1.4
1978	6	13.3	17.5	7.8	36.2	31.1	101.1	1.0	5.8	103.0	69.8	0.6
					South Extractor							
1975	8	12.8	13.8	7.3	52.0	42.5	94.5	0.9	18.7	101.2	69.5	0.5
1976	8	15.0	21.1	7.5	41.2	36.6	129.6	1.1	21.5	113.8	72.7	0.7
1977	6	13.8	26.3	7.5	27.0	23.3	132.7	1.0	20.6	115.5	46.8	1.4
1978	6	13.0	23.3	7.7	28.4	23.6	118.5	0.9	17.7	116.8	37.3	0.4
					Plot II10							
					North Extractor							
1975	5	4.4	4.3	7.4	17.7	21.7	18.8	0.3	17.8	26.6	14.2	0.2
1976	7	7.5	4.4	7.2	35.4	41.8	27.2	0.5	17.5	53.3	33.4	0.4
1977	4	6.7	5.3	7.3	29.2	35.9	29.7	0.5	16.7	55.5	21.5	0.7
1978	5	7.0	6.8	7.7	25.5	32.1	36.7	0.5	18.5	59.1	16.5	0.3
					South Extractor							
1975	3	4.8	4.7	7.3	24.7	17.5	21.7	0.5	17.0	32.1	15.1	0.3
1976	7	7.9	5.3	7.2	40.0	38.1	32.8	0.7	16.8	57.0	36.3	0.4
1977	6	7.1	6.8	7.2	28.3	32.5	37.0	0.7	17.9	58.3	21.8	0.8
1978	5	6.9	7.6	7.9	23.0	29.8	39.2	0.6	17.7	58.1	15.7	0.4

* Number of samples analyzed.

TABLE B-9. AVERAGE LEACHATE WATER COMPOSITIONS FROM THE VACUUM EXTRACTORS FOR THE ALFALFA EXPERIMENT BY YEAR FOR THE 20% LEACHING TREATMENT

Year	n*	σ	R_{Na}	pH	Cations				Anions			
					Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3
		dS m^{-1}	$(mol\ m^{-3})^{1/2}$		mol m^{-3}							
Plot II20												
North Extractor												
1975	8	8.3	7.9	7.2	38.4	33.9	47.5	0.4	20.1	67.4	35.0	0.3
1976	9	10.0	10.4	7.1	39.0	35.1	63.5	0.4	22.3	75.3	41.2	0.4
1977	5	11.7	13.6	7.1	37.7	38.1	84.4	0.5	18.5	88.4	52.7	1.3
1978	6	10.7	14.5	7.5	29.4	35.4	82.1	0.5	21.8	93.8	31.6	0.4
South Extractor												
1975	9	6.5	5.3	7.3	31.3	31.1	29.6	0.4	17.3	50.6	24.9	0.2
1976	8	8.8	6.1	7.2	43.1	42.6	39.5	0.5	18.3	68.5	40.1	0.4
1977	5	10.2	9.1	7.3	36.1	46.2	58.3	0.6	14.3	83.7	42.8	1.0
1978	6	8.9	11.0	7.7	26.3	33.7	59.3	0.6	22.7	78.6	18.5	0.3
Plot III20												
North Extractor												
1975	4	5.5	4.7	7.5	32.0	19.9	23.8	0.4	14.1	35.9	19.6	0.3
1976	6	5.7	5.0	6.9	31.8	18.9	24.9	0.4	19.9	36.1	20.6	0.2
1977	7	4.3	5.9	7.3	18.4	13.5	22.5	0.4	14.7	28.0	12.0	0.7
1978	6	3.1	4.5	7.6	11.7	9.0	14.4	0.3	16.3	12.7	6.5	0.2
South Extractor												
1975	8	5.9	5.4	7.2	32.7	19.6	27.6	0.5	16.3	39.4	25.6	0.2
1976	6	8.2	4.9	6.9	51.3	35.2	32.4	0.5	18.0	65.1	38.0	0.3
1977	7	5.3	6.6	7.3	21.0	19.0	28.8	0.5	16.3	37.2	14.6	0.6
1978	6	4.5	8.2	7.6	12.9	11.9	28.7	0.4	22.0	19.4	10.2	0.2

* Number of samples analyzed.

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TABLE B-10. RAINFALL, TOTALLED AS mm PER MONTH, FOR THE ALFALFA EXPERIMENT

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mm
1975	5	1	16	19	0	0	15	0	30	0	5	15	106
1976	1	18	5	8	1	0	30	0	23	16	9	1	111
1977	18	0	6	4	4	0	4	176	15	8	1	15	251
1978	39	10	18	3	0	0	2	2	0	14	11	13	112
Avg.	16	7	11	8	1	0	13	44	17	9	7	11	144

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TABLE B-11. METEOROLOGICAL DATA AND COEFFICIENTS REQUIRED FOR PREDICTING EVAPOTRANSPIRATION OF ALFALFA IN AN ARID CLIMATE THAT ARE NOT GIVEN IN TABLE A-5

Month	Daily* Pan Evaporation E_p mm	Daily** Solar Radiation R_s mm	Weighting Factor W	Mean Temp. T °C	Day-Night Weather Condition k_w	Daily** Net Radiation R_n mm	Wind Function f(u)	Vapor Pressure Difference e_o-e mb
Jan	2.6	4.6	0.57	10.5	0.78	1.8	0.56	6.0
Feb	3.8	6.2	0.60	12.7	0.83	3.3	0.64	6.7
Mar	5.2	7.9	0.62	14.2	0.85	4.6	0.67	7.3
Apr	7.6	10.5	0.66	16.8	0.86	6.5	0.62	7.8
May	9.0	11.4	0.70	21.4	0.89	7.2	0.57	12.4
Jun	12.2	11.8	0.78	27.8	0.93	7.7	0.65	22.2
Jul	11.8	10.5	0.80	31.8	0.93	7.2	0.68	23.7
Aug	10.4	10.3	0.80	31.1	0.91	6.8	0.66	20.9
Sep	8.3	8.3	0.78	28.3	0.88	5.6	0.59	16.5
Oct	5.6	6.9	0.72	21.7	0.85	3.8	0.55	12.8
Nov	4.0	5.4	0.62	14.6	0.82	2.6	0.57	8.8
Dec	2.6	4.2	0.57	10.1	0.80	1.8	0.52	5.5
Annual(mm)	2540							

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* Average of data from the evaporation pan located at the Yuma Mesa Experiment Station of the University of Arizona from 1975 through 1978 (R. L. Roth), personal communication, 1979) and the pan located at Roll, Arizona until 1977 and thereafter at the alfalfa experiment.

** Expressed as equivalent depth of evaporation of water.

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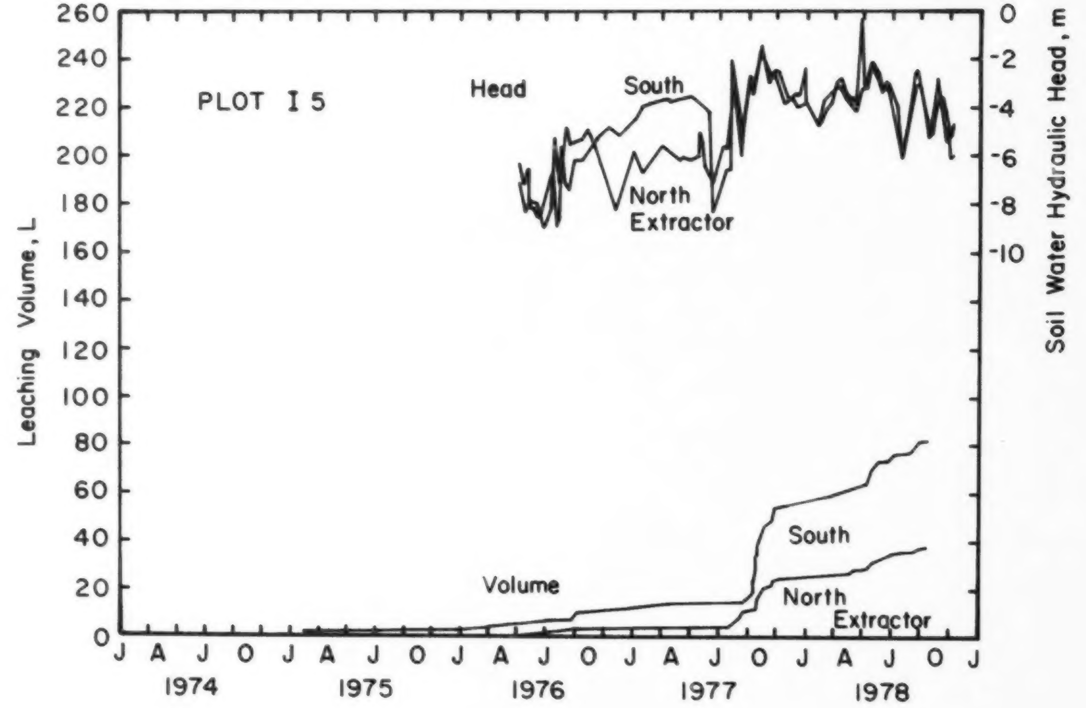

Fig. B-1a. Volume of leachate and average soil water hydraulic head for the two extractors in plot I5.

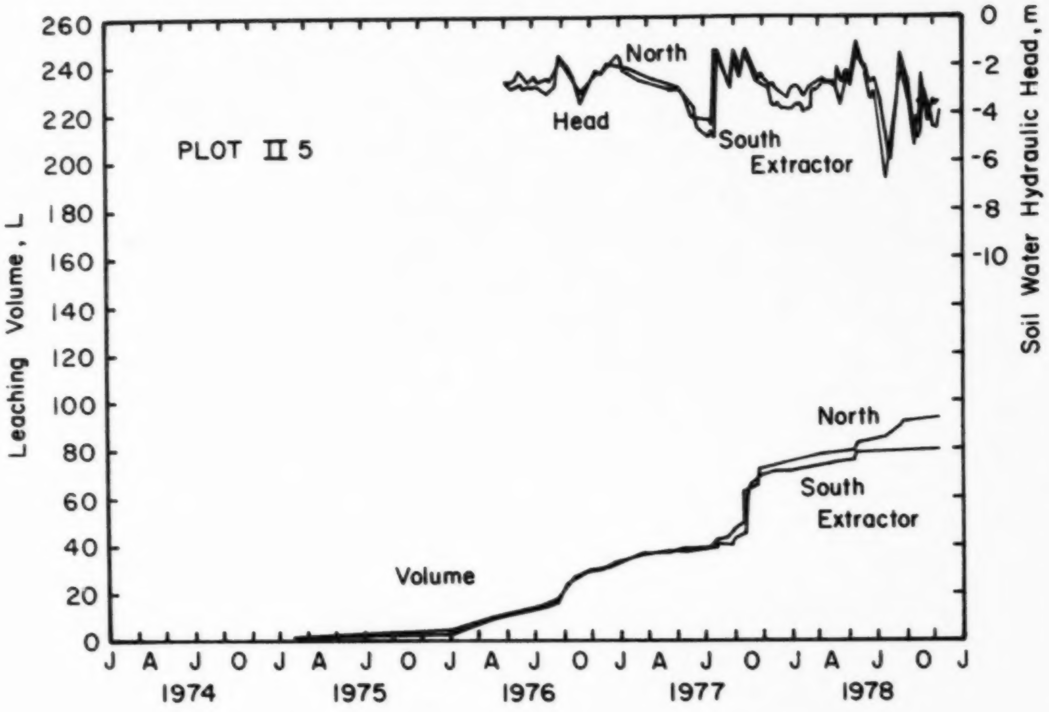

Fig. B-1b. Volume of leachate and average soil water hydraulic head for the two extractors in plot II5.

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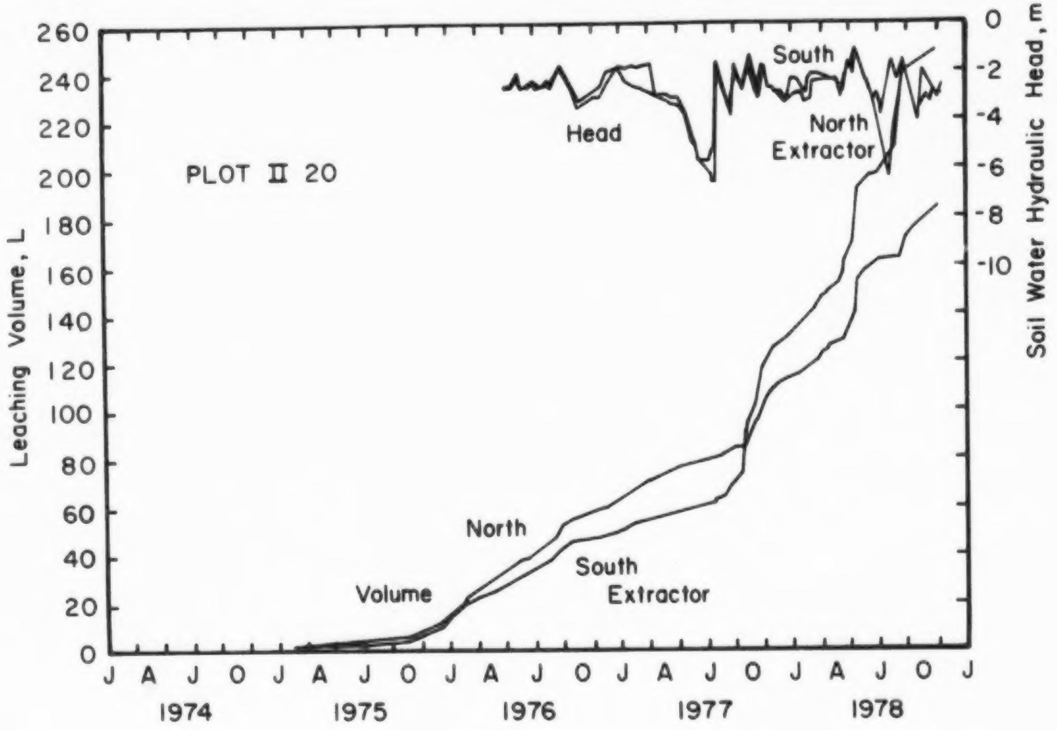

Fig. B-2a. Volume of leachate and average soil water hydraulic head for the two extractors in plot II20.

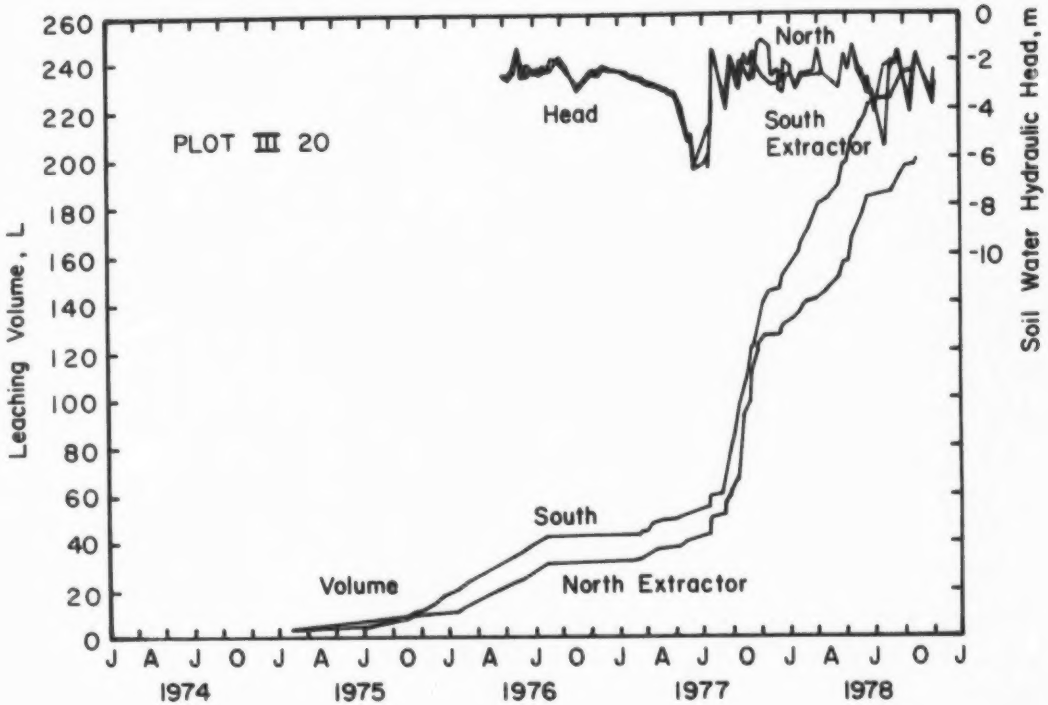

Fig. B-2b. Volume of leachate and average soil water hydraulic head for the two extractors in plot III20.

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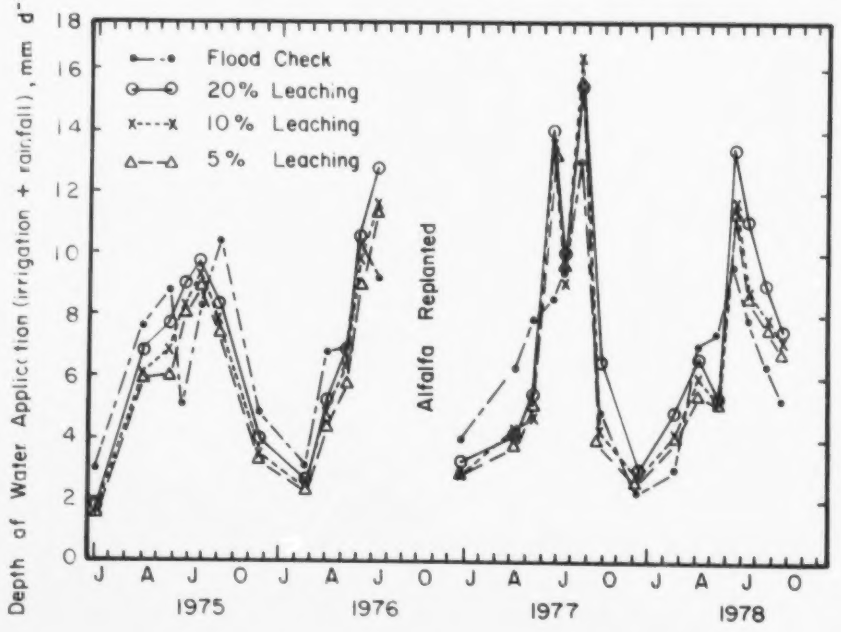

Fig. B-3. Average daily water applications (irrigation plus rainfall) for the three leaching treatments and the flood check from January 1975 to October 1978. The data points are the average application rates between alfalfa cuttings.

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